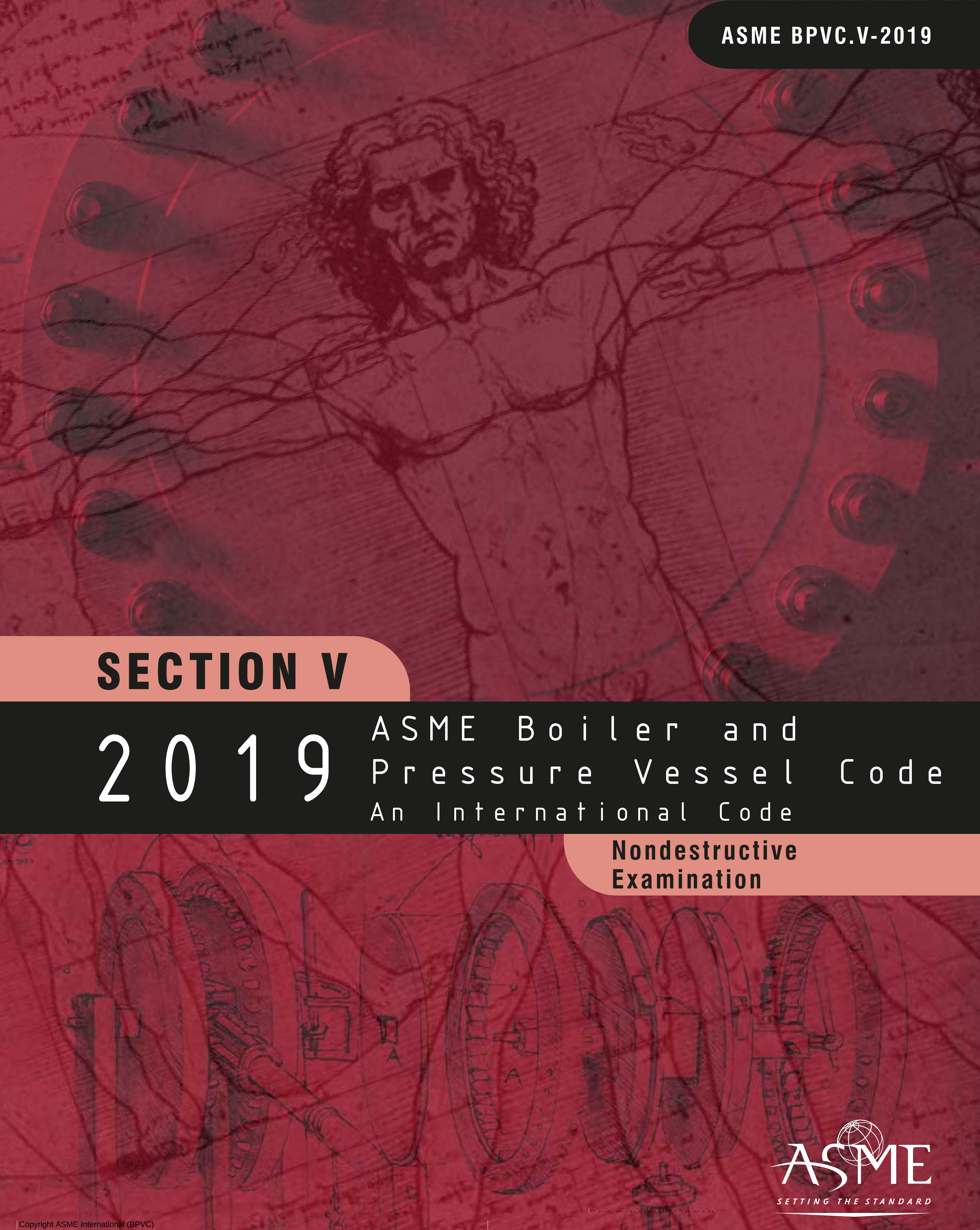

SECTION V

2019 ASME Boiler and Pressure Vessel Code

An International Code

Nondestructive Examination

ASME

SETTING THE STANDARD

Markings such as "ASME," "ASME Standard," or any other marking including "ASME," ASME logos, or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code or Standard. Use of ASME's name or logos or of the ASME Single Certification Mark requires formal ASME certification; if no certification program is available, such ASME markings may not be used. (For Certification and Accreditation Programs, see https://www.asme.org/shop/certification-accreditation.)

Items produced by parties not formally possessing an ASME Certificate may not be described, either explicitly or implicitly, as ASME certified or approved in any code forms or other document.

AN INTERNATIONAL CODE

2019 ASME Boiler & Pressure Vessel Code

2019 Edition July 1, 2019

V

NONDESTRUCTIVE EXAMINATION

ASME Boiler and Pressure Vessel Committee on Nondestructive Examination

The American Society of Mechanical Engineers

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2019

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not “approve," "certify," “rate,” or “endorse” any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable letters patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

The endnotes and preamble in this document (if any) are part of this American National Standard.

ASME Collective Membership Mark

ASME Single Certification Mark

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The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

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INTERPRETATIONS

Interpretations are issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

CODE CASES

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2019 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements. Supplements will be sent or made available automatically to the purchasers of the Code Cases books up to the publication of the 2021 Code. Code Case users can check the current status of any Code Case at http://go.asme.org/BPVCCDatabase. Code Case users can also view an index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases at http://go.asme.org/BPVCC.

FOREWORD* (19)

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating only to pressure integrity, which govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING (19)

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS (19)

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

(19) # SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES

1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the applicable Boiler and Pressure Vessel (BPV) Standards Committee (hereinafter referred to as the Committee). See the guidelines on approval of new materials under the ASME Boiler and Pressure Vessel Code in Section II, Part D for requirements for requests that involve adding new materials to the Code. See the guidelines on approval of new welding and brazing materials in Section II, Part C for requirements for requests that involve adding new welding and brazing materials ("consumables") to the Code.

Technical inquiries can include requests for revisions or additions to the Code requirements, requests for Code Cases, or requests for Code Interpretations, as described below:

(1) Code Revisions. Code revisions are considered to accommodate technological developments, to address administrative requirements, to incorporate Code Cases, or to clarify Code intent.

(2) Code Cases. Code Cases represent alternatives or additions to existing Code requirements. Code Cases are written as a Question and Reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all regulators, jurisdictions, or Owners automatically accept Code Cases. The most common applications for Code Cases are as follows:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit use of a new material for Code construction

(-c) to gain experience with new materials or alternative requirements prior to incorporation directly into the Code

(3) Code Interpretations

(-a) Code Interpretations provide clarification of the meaning of existing requirements in the Code and are presented in Inquiry and Reply format. Interpretations do not introduce new requirements.

(-b) If existing Code text does not fully convey the meaning that was intended, or conveys conflicting requirements, and revision of the requirements is required to support the Interpretation, an Intent Interpretation will be issued in parallel with a revision to the Code.

(b) Code requirements, Code Cases, and Code Interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or Owners to choose any method of design or any form of construction that conforms to the Code requirements.

(c) Inquiries that do not comply with the following guidance or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the Inquirer with no action.

2 INQUIRY FORMAT

Submittals to the Committee should include the following information:

(a) Purpose. Specify one of the following:

(1) request for revision of present Code requirements

(2) request for new or additional Code requirements

(3) request for Code Case

(4) request for Code Interpretation

(b) Background. The Inquirer should provide the information needed for the Committee's understanding of the Inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda (if applicable), paragraphs, figures, and tables. Preferably, the Inquirer should provide a copy of, or relevant extracts from, the specific referenced portions of the Code.

(c) Presentations. The Inquirer may desire to attend or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the Inquiry. Attendance at a BPV Standards Committee meeting shall be at the expense of the Inquirer. The Inquirer's attendance or lack of attendance at a meeting will not be used by the Committee as a basis for acceptance or rejection of the Inquiry by the Committee. However, if the Inquirer's request is unclear, attendance by the Inquirer or a representative may be necessary for the Committee to understand the request sufficiently to be able to provide an Interpretation. If the Inquirer desires to make a presentation at a Committee meeting, the Inquirer should provide advance notice to the Committee Secretary, to ensure time will be allotted for the presentation in the meeting agenda. The Inquirer should consider the need for additional audiovisual equipment that might not otherwise be provided by the Committee. With sufficient advance notice to the Committee Secretary, such equipment may be made available.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions should include the following information:

(a) Requested Revisions or Additions. For requested revisions, the Inquirer should identify those requirements of the Code that they believe should be revised, and should submit a copy of, or relevant extracts from, the appropriate requirements as they appear in the Code, marked up with the requested revision. For requested additions to the Code, the Inquirer should provide the recommended wording and should clearly indicate where they believe the additions should be located in the Code requirements.

(b) Statement of Need. The Inquirer should provide a brief explanation of the need for the revision or addition.

(c) Background Information. The Inquirer should provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request, that will allow the Committee to adequately evaluate the requested revision or addition. Sketches, tables, figures, and graphs should be submitted, as appropriate. The Inquirer should identify any pertinent portions of the Code that would be affected by the revision or addition and any portions of the Code that reference the requested revised or added paragraphs.

4 CODE CASES

Requests for Code Cases should be accompanied by a statement of need and background information similar to that described in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure) should be described. In addition, it is important that the request is in connection with equipment that will bear the ASME Single Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and should be written as a Question and a Reply, in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Editions and Addenda (if applicable) to which the requested Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations should be accompanied by the following information:

(1) Inquiry. The Inquirer should propose a condensed and precise Inquiry, omitting superfluous background information and, when possible, composing the Inquiry in such a way that a "yes" or a "no" Reply, with brief limitations or conditions, if needed, can be provided by the Committee. The proposed question should be technically and editorially correct.

(2) Reply. The Inquirer should propose a Reply that clearly and concisely answers the proposed Inquiry question. Preferably, the Reply should be "yes" or "no," with brief limitations or conditions, if needed.

(3) Background Information. The Inquirer should provide any need or background information, such as described in 3(b) and 3(c), respectively, for Code revisions or additions, that will assist the Committee in understanding the proposed Inquiry and Reply.

If the Inquirer believes a revision of the Code requirements would be helpful to support the Interpretation, the Inquirer may propose such a revision for consideration by the Committee. In most cases, such a proposal is not necessary.

(b) Requests for Code Interpretations should be limited to an Interpretation of a particular requirement in the Code or in a Code Case. Except with regard to interpreting a specific Code requirement, the Committee is not permitted to consider consulting-type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation

(3) a request seeking the rationale for Code requirements

6 SUBMITTALS

(a) Submittal. Requests for Code Interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt. If the Inquirer is unable to use the online form, the Inquirer may mail the request to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Two Park Avenue
New York, NY 10016-5990

All other Inquiries should be mailed to the Secretary of the BPV Committee at the address above. Inquiries are unlikely to receive a response if they are not written in clear, legible English. They must also include the name of the Inquirer and the company they represent or are employed by, if applicable, and the Inquirer's address, telephone number, fax number, and e-mail address, if available.

(b) Response. The Secretary of the appropriate Committee will provide a written response, via letter or e-mail, as appropriate, to the Inquirer, upon completion of the requested action by the Committee. Inquirers may track the status of their Interpretation Request at http://go.asme.org/Interpretations.

PERSONNEL
ASME Boiler and Pressure Vessel Standards Committees, Subgroups, and Working Groups

(**19**)

January 1, 2019

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As of January 1, 2019

E07 ON NONDESTRUCTIVE TESTING

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SUMMARY OF CHANGES

Errata to the BPV Code may be posted on the ASME website to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published by ASME at http://go.asme.org/BPVCerrata.

Changes given below are identified on the pages by a margin note, **(19)**, placed next to the affected area.

The Record Numbers listed below are explained in more detail in "List of Changes in Record Number Order" following this Summary of Changes.

Page	*Location*	*Change (Record Number)*
xxv	List of Sections	Updated
xxvii	Foreword	Penultimate paragraph revised
xxix	Statement of Policy on the Use of the ASME Single Certification Mark and Code Authorization in Advertising	Revised
xxix	Statement of Policy on the Use of ASME Marking to Identify Manufactured Items	Revised
xxx	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	In para. 4, third sentence revised
xxxiii	Personnel	Updated
lv	ASTM Personnel	Updated
1	T-120	Subparagraphs (b), (e)(1), (e)(2), and (g) revised *(17-3215, 18-536, 18-1774, 18-1775)*
2	T-150	Subparagraph (d) revised *(17-682)*
3	T-170	Subparagraph (a) revised *(18-1967)*
5	I-121	Definitions of *footcandle (fc)*, *lux (lx)*, *unprocessed data*, and *visible light (white light)* added *(16-2667, 16-2901, 17-425)*
9	I-121.2	*(1)* Definitions of *adaptive total focusing method (ATFM)*, *classic full matrix capture (FMC)*, *display grid density*, *elementary full matrix capture*, *encoded manual ultrasonic examinations (EMUT)*, *full matrix capture (FMC)*, *full matrix capture (FMC) frame*, *full matrix capture/total focusing method (FMC/TFM)*, *grid density*, *matrix capture (MC)*, *total focusing method (TFM)*, *total focusing method (TFM) datum point*, *total focusing method (TFM) grid/image*, and *total focusing method (TFM) settings* added *(12-1469, 16-1730, 18-1336)* *(2)* Definition of *manual ultrasonic examinations (MUT)* revised *(16-1730)*

Page	Location	Change (Record Number)
		(3) In definition of *S-scan*, definitions of subterms *beam movement* and *data display* redesignated by errata *(17-2040)*
14	I-121.4	*(1)* Definition of *direct current (DC)* added *(17-2901)* *(2)* Definitions of *half-wave rectified alternating current (HWAC)* and *rectified current* revised *(17-2901)*
15	I-121.5	Definitions of *array coil topology*, *channel standardization*, *eddy current array (ECA)*, *eddy current channel*, and *fill factor (FF)* added *(17-1199, 18-343)*
16	I-121.6	Definition of *lux (lx)* deleted *(17-425)*
16	I-121.7	Definitions of *foreline*, *HMSLD*, *mode lock*, *multiple mode*, and *test mode* added *(14-2283)*
25	II-110	Last sentence revised *(18-536)*
25	II-121	Revised *(18-536, 18-1680)*
26	II-124.5	Added *(18-536)*
26	Table II-121-1	*(1)* General Note (d) revised *(18-1878)* *(2)* General Note (e) added *(18-1680)*
27	Table II-121-2	*(1)* Last row added *(18-536)* *(2)* Note (1) revised *(18-536)*
27	Table II-122.2	Last row added *(18-536)*
28	Mandatory Appendix II, Supplement A (Article 1)	Added *(18-536)*
30	Mandatory Appendix III (Article 1)	Added *(18-1774)*
35	Mandatory Appendix IV (Article 1)	Added *(18-1775)*
39	T-223	In first sentence, height dimensions revised *(17-382)*
39	T-224	Revised *(17-347)*
41	T-262.1	First paragraph revised *(17-847)*
44	T-276.2	Subparagraph (a) revised *(17-2020)*
44	T-277.1	Subparagraph (d) revised *(17-2625)*
46	T-283.1	Second paragraph added *(15-248)*
63	VIII-221.1	Subparagraphs (i) and (j) added *(18-967)*
63	VIII-221.2	Revised *(18-967)*
64	VIII-283.1	Second paragraph added *(15-248)*
66	Mandatory Appendix VIII, Supplement A (Article 2)	Added *(18-967)*
68	IX-221.1	Subparagraphs (k) and (l) added *(18-968)*
68	IX-221.2	Revised *(18-968)*
70	IX-277.1	Subparagraphs (b), (c), and (d) revised *(17-3193)*

Page	Location	Change (Record Number)
70	IX-281.1	Revised *(17-371)*
70	IX-283.1	Second paragraph added *(15-248)*
72	Mandatory Appendix IX, Supplement A (Article 2)	Added *(18-968)*
84	T-420	Subparagraphs (e) and (f) added *(16-2752, 18-1456)*
84	T-421	Revised *(16-2752)*
90	Figure T-434.3-2	In Note (2), second cross-reference revised *(17-381)*
109	IV-421	Revised *(16-2752)*
110	Table IV-421	Revised in its entirety *(16-2752)*
109	IV-422	Added *(16-2752)*
109	IV-492	*(1)* Subparagraph (b) revised *(16-2748)* *(2)* Subparagraphs (d) and (e) added *(16-2748)*
111	V-421	Revised *(16-2752)*
112	Table V-421	Revised in its entirety *(16-2752)*
111	V-422	Revised in its entirety *(16-2752)*
113	V-492	*(1)* Subparagraph (b) revised *(16-2749)* *(2)* Subparagraph (d) added, and former subpara. (d) revised and redesignated as (e) *(16-2749)*
114	VII-421	Revised in its entirety *(16-2752)*
114	Table VII-421	Deleted *(16-2752)*
114	VII-423	Revised *(17-2029)*
115	VII-492	*(1)* Subparagraph (a) revised *(16-2750)* *(2)* Subparagraphs (f) and (g) added *(16-2750)*
116	VIII-410	Last sentence added *(18-1892)*
116	VIII-421	Revised in its entirety *(16-2752, 18-1726)*
116	Table VIII-421	Deleted *(16-2752)*
116	VIII-423	Revised *(17-2029)*
116	VIII-432.1	"Normal frequency" corrected by errata to "nominal frequency" *(17-2105)*
118	VIII-492	*(1)* Subparagraph (a) revised *(16-2751)* *(2)* Subparagraphs (f) and (g) added *(16-2751)*
124	Mandatory Appendix XI (Article 4)	Added *(16-2755, 18-1441, 18-2154, 18-2480, 18-2715)*
148	Nonmandatory Appendix F (Article 4)	Added *(17-845)*
215	IV-531.2	In table, title of first column revised *(17-2958)*
220	T-676	T-676.1, T-676.3, and T-676.4 revised *(16-2142, 17-425, 17-1198)*
222	III-630	In first paragraph, second sentence revised *(17-848)*
224	T-710	First paragraph revised *(17-905)*

Page	*Location*	*Change (Record Number)*
224	T-731	Subparagraph (b) revised *(17-2893)*
228	T-762	Subparagraphs (b) and (c) revised *(17-903)*
233	T-777	T-777.1, T-777.2, and T-777.3(c) revised *(16-2142, 17-425)*
236	I-730	Paragraphs editorially redesignated
242	V-720	Paragraphs editorially redesignated
242	V-721	Paragraphs editorially redesignated
246	T-810	Subparagraphs (i), (j), (k), and (l) added *(17-2039, 17-2900)*
247	Mandatory Appendix II (Article 8)	Paragraphs and associated figures within II-830, II-840, II-860, II-880, and II-890 editorially redesignated
256	IV-810	Last sentence revised *(17-906)*
264	VII-830	Paragraphs and associated figure editorially redesignated
268	Mandatory Appendix VIII (Article 8)	Title revised *(17-2039)*
269	Table VIII-821	In first row, "and grade/temper" deleted by errata *(17-2896)*
270	VIII-850	Paragraphs editorially redesignated
272	VIII-880	Paragraphs editorially redesignated
272	VIII-890	Paragraphs editorially redesignated
274	Mandatory Appendix IX (Article 8)	Added *(17-2900)*
279	Mandatory Appendix X (Article 8)	Added *(17-2900)*
283	Table T-921	Fifth row revised *(18-1340)*
284	T-952	Fourth sentence revised *(17-425)*
284	T-953	Last sentence revised *(17-1688)*
284	T-955	Added *(17-1688)*
284	T-980	Paragraphs editorially redesignated
284	T-991	Paragraphs editorially redesignated
288	Table I-1021	Fifth row revised *(17-2902)*
290	Table II-1021	Fifth row revised *(17-2903)*
293	Table III-1021	Fourth row revised *(17-2904)*
296	Table IV-1021	Fifth row revised *(17-2905)*
299	Table V-1021	Fifth row revised *(17-2906)*
301	Table VI-1021	Fifth row revised *(17-2907)*
304	Table VIII-1021	Fifth row revised *(17-2908)*
306	Mandatory Appendix IX (Article 10)	Revised in its entirety *(15-265, 17-2909, 17-2910)*
312	Mandatory Appendix XI (Article 10)	Added *(16-484)*

Page	*Location*	*Change (Record Number)*
338	T-1220	Paragraphs editorially redesignated
338	T-1224	Paragraphs editorially redesignated
340	T-1273.1	Title editorially added
345	I-1210	Paragraphs editorially redesignated
367	III-1332	Paragraphs editorially redesignated
367	III-1360	Titles editorially added to III-1361 through III-1364
368	III-1382	Paragraphs editorially redesignated
374	VI-1330	Titles editorially added to VI-1331.1, VI-1331.2, and VI-1332.1
394	T-1710	In subpara. (d), cross-reference revised *(18-344)*
395	T-1762	Paragraphs editorially redesignated
401	T-1863	Paragraphs editorially redesignated
459	SE-1030/SE-1030M	Revised in its entirety *(17-420)*
503	SE-1416	Revised in its entirety *(17-2952)*
517	SE-2597/SE-2597M	Added *(16-2096)*
537	SA-388/SA-388M	Revised in its entirety *(17-417)*
547	SA-435/SA-435M	Revised in its entirety *(18-1289)*
551	SA-577/SA-577M	Revised in its entirety *(18-1290)*
555	SA-578/SA-578M	Revised in its entirety *(18-1291)*
577	SB-548	*(1)* ASTM reapproval date revised *(17-2957)* *(2)* Title editorially corrected
609	SE-317	Added *(14-1018)*
623	SE-797/SE-797M	Revised in its entirety *(17-416)*
667	SD-516	Revised in its entirety *(17-423)*
673	SD-808	Revised in its entirety *(17-424)*
779	SE-650/SE-650M	Revised in its entirety *(17-2970)*
821	SE-1118/SE-1118M	Revised in its entirety *(17-2971)*
835	SE-1139/SE-1139M	Revised in its entirety *(17-2972)*
843	SE-1211/SE-1211M	Revised in its entirety *(17-2973)*
862	Article 30	Editorially deleted
865	SE-2261/SE-2261M	Revised in its entirety *(17-2898)*
881	SE-2096/SE-2096M	Revised in its entirety *(17-2897)*
917	A-1	Revised *(17-334)*

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
12-1469	Added three definitions for FMC/TFM in I-121.2 to support the inclusion of FMC/TFM into the ASME Codes.
14-1018	Adopted ASTM E317-16 as SE-317-16.
14-2283	Added definitions for "foreline," "HMSLD," "mode lock," "multiple mode," and "test mode."
15-248	Added a sentence in Article 2 to clarify that the essential wire shall be visible within the area of interest representing the thickness used for determining the essential wire (inclusive of allowable density and brightness variations).
15-265	Updated Article 10, Mandatory Appendix IX with a substantial number of changes including, but not limited to, the following: Revised text to acknowledge and set standards for the use of the multimode helium mass spectrometers that are now the common design. Added an equation to calculate the instrument sensitivity (the requirement is not new, but agreed means of calculating are now available). Improved system calibration practices. Improved helium concentration measurement and use of that data. Revised text to address the use of high-speed booster pumps (turbomolecular or diffusion pumps). Added other improved practices that have come into use over the many years since this Appendix was last reviewed.
16-484	Added Mandatory Appendix XI in Article 10 to address the helium leak test of sealed objects that contain helium, such as a package that is welded closed with helium as the gas portion of the package contents.
16-1730	Added a definition for "encoded manual ultrasonic examinations." Revised the definition for "Manual Ultrasonic Examinations."
16-2096	Adopted ASTM E2597-14 as SE-2597-14.
16-2142	Added and revised several sections changing "black light" to "UV-A light" and revising various words to make Articles 6 and 7 have the same content except for references to other paragraphs. Added new paragraphs for LED lights and revised the designations of those and old paragraphs that changed because of the insertions.
16-2667	Added a definition for "visible light" in I-121.
16-2748	Added additional reporting requirements in IV-492.
16-2749	Added additional reporting requirements in V-492.
16-2750	Added additional reporting requirements and clarified the linkage to Appendix V requirements in VII-492.
16-2751	Added additional reporting requirements and clarified the linkage to Article 4, Mandatory Appendix V requirements.
16-2752	Consolidated the variables for phased array examinations in a user-friendly format. Added several variables based on lessons learned, qualification experiences, and enhanced equipment capabilities. Clarified the need for scan plans in Article 4, Mandatory Appendix IV. Revised IV-421 to delete the reference to Table T-421. Revised IV-421.2 to reference only Table IV-421. Inserted IV-422 to clarify the need for and use of a scan plan. Revised Table IV-421 to incorporate Table T-421 and supplemented the listed variables to incorporate variables from Table T-421 as a single source of procedure requirements. Revised V-421 to delete the reference to Table T-421. Revised V-421.2 to reference only Table V-421. Inserted V-422 to clarify the need for and use of a scan plan. Revised Table V-421 to incorporate Tables T-421, VII-421, and VIII-421 and supplemented the listed variables to incorporate variables from Table T-421 as a single source of procedure requirements. Revised VII-421.1 to delete the reference to Table T-421 and refer to Table V-421. Revised VII-421.2 to delete the reference to Table T-421 and refer to Table V-421. Deleted Table VII-421. Revised VIII-421.1 to delete the reference to Table T-421 and refer to Table V-421. Revised VIII-421.2 to delete the reference to Table T-421 and refer to Table V-421. Deleted Table VIII-421.
16-2755	Added Mandatory Appendix XI in Article 4.
16-2901	Added a definition for "unprocessed data."
17-334	Revised the first sentence in A-1 to change the term "Nonmandatory Appendix" to "Section."

Record Number	Change
17-347	Replaced the word "organization's" with "Manufacturer's" in the second sentence of T-224 and added "An NDE subcontractor's name or symbol may also be used together with that of the Manufacturer" as the third sentence.
17-371	Revised IX-281.1 to address the use of DDSs that are in motion, taking into account the use of image stacking (multiple exposures to generate a final compounded image).
17-381	Changed the reference in Figure T-434.3-2, Note (2) from "T-464.1.2" (incorrectly directing the user to the paragraph for setting up a DAC curve with notches) to "T-464.1.3" (correctly directing the user to the paragraph for setting up a DAC curve using side-drilled holes).
17-382	Revised T-223 to reflect a minimum dimension of $^7/_{16}$ in. (11 mm) for the required height of a lead symbol "B" for the determination of the presence of backscattered radiation.
17-416	Updated SE-797 to ASTM E797-15.
17-417	Updated SA-388 to ASTM A388-16a.
17-420	Updated SE-1030 to ASTM E1030-15.
17-423	Updated SD-516 to ASTM D516-16.
17-424	Updated SD-808 to ASTM D808-16.
17-425	Revised Articles 6, 7, and 9 to change the lx values for 100 fc to 1 076 lx. Revised the value for 2 fc in T-777.3 to 21.5 lx. Deleted the definition for lux in Article 1, Appendix I, Visual Definitions and placed it in the General Definitions and added a general definition for "footcandle."
17-682	Revised the first sentence in T-150(d) to require the qualification demonstration be performed prior to the acceptance of production examinations. Editorially revised to begin sublist of items with a new second sentence.
17-845	Added Nonmandatory Appendix F in Article 4.
17-847	Revised "90 days" to "3 months" in T-262.1.
17-848	Revised "9.5 mm" to "10 mm" in III-630.
17-903	Revised T-762 to clarify the intent of the maximum pole spacing and yoke contact for electromagnetic and permanent yokes.
17-905	Revised T-710 to reflect the correct title of SE-709 as adopted.
17-906	Revised IV-810 to reflect the correct title of SE-243 as adopted.
17-1198	Revised T-676.1.
17-1199	Added definitions for "O.D. encircling coils" and "I.D. probes/coils."
17-1688	Added the requirement for the calibration of light meters as required and as in Articles 6 and 7. Revised T-953 to include light intensity along with resolution.
17-2020	Revised T-276.2(a) to remove the word "actual" in the first sentence and to add a weld condition clarification in the second sentence.
17-2029	Added requirements for personnel certification for those who approve setups and perform calibrations to VII-423 and VIII-423.
17-2039	Added references to Mandatory Appendices VII and VIII to T-810. Revised the title of Article 8, Mandatory Appendix VIII.
17-2040	Errata correction. See Summary of Changes for details.
17-2105	Errata correction. See Summary of Changes for details.
17-2625	Changed wording from "... is across the length of ..." to "... are transverse to the longitudinal axis of ..."
17-2893	Replaced "should" with "shall" in T-731(b). Added the following after "with" in T-731(b): "the applicable specifications listed in SE-709, para. 2.2."
17-2896	Errata correction. See Summary of Changes for details.
17-2897	Updated SE-2096/SE-2096M to ASTM E2096/E2096M-16.
17-2898	Updated SE-2261/SE-2261M to ASTM E2261/E2261M-17.
17-2900	Amended T-810. Added Mandatory Appendices IX and X in Article 8.
17-2901	Added definition for "direct current (DC)" to Article 1, Mandatory Appendix I. Revised definitions for "half-wave rectified alternating current (HWAC)" and "rectified current" for consistency.
17-2902	Reclassified "personnel performance qualification requirements, when required" as a nonessential variable in Table I-1021.
17-2903	Reclassified "personnel performance qualification requirements, when required" as a nonessential variable in Table II-1021.

Record Number	Change
17-2904	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table III-1021.
17-2905	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table IV-1021.
17-2906	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table V-1021.
17-2907	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table VI-1021.
17-2908	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table VIII-1021.
17-2909	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table IX-1021.
17-2910	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table IX-1021.
17-2952	Adopted ASTM E1416-16a as SE-1416-16a.
17-2957	Updated SB-548 to ASTM B548-03 (2017).
17-2958	Revised first column head to “Bolt Diameter” in the table in IV-531.2.
17-2970	Updated SE-650/SE-650M to ASTM E650/E650M-17.
17-2971	Updated SE-1118/SE-1118M to ASTM E1118/E1118M-16.
17-2972	Updated SE-1139 to ASTM E1139/E1139M-17.
17-2973	Updated SE-1211/SE-1211M to ASTM E1211/E1211M-17.
17-3193	Added wording to IX-277.1(b), IX-277.1(c), and IX-277.1(d) to clearly indicate the requirements for in-motion techniques.
17-3215	Replaced “are nonmandatory” with “are not mandatory” and added “Where there is a conflict between Subsection A and Subsection B, the requirements of Subsection A take precedence” in T-120(b).
18-343	Added definitions to support ASME codes related to eddy current array (ECA) inspection applications.
18-344	Revised T-1710(d) by changing “Article 26” to “Article 32” to reflect the editorial movement of SE-2096 from Article 26 to Article 32.
18-536	Revised T-120(g), II-110, and II-121. Added II-124.5. Revised Tables II-121.2 and II-122.2. Added Article 1, Mandatory Appendix II, Supplement A.
18-967	Added subparas. VIII-221.1(i) and VIII-221.1(j). Revised VIII-221.2 to reference new Supplement A for procedure demonstration.
18-968	Added subparas. IX-221.1(k) and IX-221.1(l). Revised IX-221.2 to reference Supplement A for procedure demonstration.
18-1289	Updated SA-435/SA-435M to ASTM A435/A435M-17.
18-1290	Updated SA-577/SA-577M to ASTM A577/A577M-17.
18-1291	Updated SA-578/SA-578M to ASTM A578/A578M-17.
18-1336	Added 10 definitions for FMC/TFM in I-121.2 to support the inclusion of FMC/TFM.
18-1340	Reclassified “personnel performance qualification requirements, when required” as a nonessential variable in Table T-921.
18-1441	Deleted part of XI-450 that is redundant of XI-421.2. Added reference to T-150(d) in XI-421.2. Replaced “are” with “shall be” in XI-462.4(a). Corrected typos in XI-421.1, XI-421.2, XI-482(a), and Figure XI-434.
18-1456	Added T-420(e) to reference Article 4, Mandatory Appendix V.
18-1680	Added General Note (e) in Table II-121-1. Added second and third paragraphs in II-121.
18-1726	Added “and shall comply with Article 1, T-150(d)” to the first sentence of VIII-421.2.
18-1774	Replaced “2006 Edition” of ASNT SNT-TC-1A with “2016 Edition” and added “Mandatory Appendix III” in T-120.
18-1775	Replaced “2006 Edition” of ANSI/ASNT CP-189 with “2016 Edition” and added “Mandatory Appendix IV” in T-120.

Record Number	Change
18-1878	Revised Table II-121-1, General Note (d) to establish the minimum additional training hours for a Level II examiner certified in one Radiography technique to achieve certification Level II in another technique as 24 hr of technique-specific training, plus 16 hr of manufacturer-specific hardware/software training for each system/software to be used, plus 10 practical examination specimens, as called out in II-122.1(b), per additional technique.
18-1892	Added the following sentence in VIII-410: "When fracture-mechanics-based acceptance criteria are used with the full matrix capture (FMC) ultrasonic technique, Mandatory Appendix XI shall apply."
18-1967	Revised to remove gender-specific pronouns.
18-2154	Changed the reference from "Nonmandatory Appendix T" to "Nonmandatory Appendix F" in XI-410.
18-2480	Added XI-467 and added second sentence to XI-471.1.
18-2715	Deleted reference to IX-492 from XI-492.

CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
  - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

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SUBSECTION A
NONDESTRUCTIVE METHODS OF EXAMINATION

ARTICLE 1
GENERAL REQUIREMENTS

T-110 SCOPE

(a) This Section of the Code contains requirements and methods for nondestructive examination (NDE), which are Code requirements to the extent they are specifically referenced and required by other Code Sections or referencing documents. These NDE methods are intended to detect surface and internal imperfections in materials, welds, fabricated parts, and components. They include radiographic examination, ultrasonic examination, liquid penetrant examination, magnetic particle examination, eddy current examination, visual examination, leak testing, and acoustic emission examination. See Nonmandatory Appendix A of this Article for a listing of common imperfections and damage mechanisms, and the NDE methods that are generally capable of detecting them.

(b) For general terms such as *inspection, flaw, discontinuity, evaluation*, etc., refer to Mandatory Appendix I.

(c) New editions of Section V may be used beginning with the date of issuance and become mandatory 6 months after the date of issuance unless modified by the referencing document.

(d) Code Cases are permissible and may be used, beginning with the date of approval by ASME. Only Code Cases that are specifically identified as being applicable to this Section may be used. At the time a Code Case is applied, only the latest revision may be used. Code Cases that have been incorporated into this Section or have been annulled shall not be used, unless permitted by the referencing Code. Qualifications using the provisions of a Code Case remain valid after the Code Case is annulled. The Code Case number shall be listed on the NDE Procedure or Personnel Certification, as applicable.

T-120 GENERAL (19)

(a) Subsection A describes the methods of nondestructive examination to be used if referenced by other Code Sections or referencing documents.

(b) Subsection B lists Standards covering nondestructive examination methods which have been accepted as standards. These standards are not mandatory unless specifically referenced in whole or in part in Subsection A or as indicated in other Code Sections or referencing documents. Where there is a conflict between Subsection A and Subsection B, the requirements of Subsection A take precedence.

(c) Any reference to a paragraph of any Article in Subsection A of this Section includes all of the applicable rules in the paragraph.[1] In every case, reference to a paragraph includes all the subparagraphs and subdivisions under that paragraph.

(d) Reference to a standard contained in Subsection B is mandatory only to the extent specified.[2]

(e) For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which shall be in accordance with one of the following documents:

(1) SNT-TC-1A (2016 Edition),[3] Personnel Qualification and Certification in Nondestructive Testing, as amended by Mandatory Appendix III; or

(2) ANSI/ASNT CP-189 (2016 Edition),[3] ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, as amended by Mandatory Appendix IV

(f) National or international central certification programs, such as the ASNT Central Certification Program (ACCP) or ISO 9712:2012-based programs, may be alternatively used to fulfill the training, experience, and examination requirements of the documents listed in (e) as specified in the employer's written practice.

(g) In addition to the requirements described in (e) or (f) above, if the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC) are to be used, the training, experience, and examination requirements found in Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable.

(h) Alternatively, performance-based qualification programs, in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program, may be used for training, experience, examination, and certification activities as specified in the written practice.

(i) When the referencing Code Section does not specify qualifications or does not reference directly Article 1 of this Section, qualification may simply involve a demonstration to show that the personnel performing the nondestructive examinations are competent to do so in accordance with the organization's established procedures.

(j) The user of this Article is responsible for the qualification and certification of NDE Personnel in accordance with the requirements of this Article. The organization's[4] Quality Program shall stipulate how this is to be accomplished. Qualifications in accordance with a prior edition of SNT-TC-1A, or CP-189 are valid until recertification. Recertification or new certification shall be in accordance with the edition of SNT-TC-1A or CP-189 specified in (e) above. When any of the techniques included in (g) above are used, the additional requirements of that paragraph shall also apply.

(k) Limited certification of nondestructive examination personnel who do not perform all of the operations of a nondestructive method that consists of more than one operation, or who perform nondestructive examinations of limited scope, may be based on fewer hours of training and experience than recommended in SNT-TC-1A or CP-189. Any limitations or restrictions placed upon a person's certification shall be described in the written practice and on the certification.

(l) Either U.S. Customary Units or SI Units may be used for compliance with all requirements of this edition, but one system shall be used consistently throughout for all phases of construction.

(1) Either the U.S. Customary Units or SI Units that are listed in Section V Mandatory Appendix II (in the rear of Section V and listed in other Code books) are identified in the text, or are identified in the nomenclature for equations shall be used consistently for all phases of construction (e.g., materials, design, fabrication, and reports). Since values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary Units and SI Units.

(2) When SI Units are selected, U.S. Customary values in referenced specifications that do not contain SI Units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

T-130 EQUIPMENT

It is the responsibility of the Code User to ensure that the examination equipment being used conforms to the requirements of this Code Section.

T-150 PROCEDURE (19)

(a) When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be performed following a written procedure. A procedure demonstration shall be performed to the satisfaction of the Inspector. When required by the referencing Code Section, a personnel demonstration may be used to verify the ability of the examiner to apply the examination procedure. The examination procedure shall comply with the applicable requirements of this Section for the particular examination method. Written procedures shall be made available to the Inspector on request. At least one copy of each procedure shall be readily available to the Nondestructive Examination Personnel for their reference and use.

(b) The nondestructive examination methods and techniques included in this Section are applicable to most geometric configurations and materials encountered in fabrication under normal conditions. Whenever special configurations or materials require modified methods and techniques, the organization shall develop special procedures which are equivalent or superior to the methods and techniques described in this Code Section, and which are capable of producing interpretable examination results under the special conditions. Such special procedures may be modifications or combinations of methods described or referenced in this Code Section. A procedure demonstration shall be performed to verify the technique is capable of detecting discontinuities under the special conditions equal to the capabilities of the method when used under more general conditions. These special procedures shall be submitted to the Inspector for acceptance when required by the referencing Code Section, and shall be adopted as part of the Manufacturer's quality control program.

(c) When a referencing Code Section requires an examination to be performed in accordance with the requirements of this Section, it shall be the responsibility of the organization to establish nondestructive examination procedures and personnel qualification and certification procedures conforming to the referenced requirements.

(d) When qualification of the written examination procedure is required by the referencing Code Section, a qualification demonstration shall be performed prior to acceptance of production examinations. The qualification demonstration shall be performed

(1) under the control and supervision of a Level III Examiner who is qualified and certified for performing the examination method and technique specified by the procedure, and shall be witnessed by the Inspector. The supervising Level III may be an employee of the qualifying organization or a subcontractor organization.

(2) on a minimum of one test specimen having flaws whose size, location, orientation, quantity, and characterization have been determined prior to the demonstration and are known only by the supervising Level III Examiner.

(-a) The maximum acceptable flaw size, required flaw orientation, and minimum number of flaws shall be as specified by the referencing Code Section.

(-b) Natural flaws are preferred over artificial flaws whenever possible.

(3) by a Level II or Level III Examiner (other than the supervising Level III) who is qualified and certified to perform the examination method and technique specified by the written procedure.

The procedure shall be considered qualified when the supervising Level III and the Inspector are satisfied that indications produced by the demonstrated procedure effectively reveal the size, location, orientation, quantity, and characterization of the flaws known to be present in the examined test specimen.

The qualification demonstration shall be documented as required by the referencing Code Section and by this Section, as set forth in the applicable Article for the examination method and the applicable Appendix for the specified examination technique. The qualification document shall be annotated to indicate qualification of the written procedure, and identify the examined test specimen. The name and/or identity and signature of the supervising Level III and the witnessing Inspector shall be added to indicate their acceptance of the procedure qualification.

T-160 CALIBRATION

(a) The organization shall assure that all equipment calibrations required by Subsection A and/or Subsection B are performed.

(b) When special procedures are developed [see T-150(a)], the Code User shall specify what calibration is necessary, when calibration is required.

(19) T-170 EXAMINATIONS AND INSPECTIONS

(a) The Inspector concerned with the fabrication of the vessel or pressure part shall have the duty of verifying to the Inspector's satisfaction that all examinations required by the referencing Code Section have been made to the requirements of this Section and the referencing document(s). The Inspector shall have the right to witness any of these examinations to the extent stated in the referencing document(s). Throughout this Section of the Code, the word *Inspector* shall be as defined and qualified as required by the referencing Code Section or referencing document(s).

(b) The special distinction established in the various Code Sections between *inspection* and *examination* and the personnel performing them is also adopted in this Code Section. In other words, the term *inspection* applies to the functions performed by the *Inspector*, but the term *examination* applies to those quality control functions performed by personnel employed by the organization. One area of occasional deviation from these distinctions exists. In the ASTM Standard Methods and Recommended Practices incorporated in this Section of the Code by reference or by reproduction in Subsection B, the words *inspection* or *Inspector*, which frequently occur in the text or titles of the referenced ASTM documents, may actually describe what the Code calls *examination* or *examiner*. This situation exists because ASTM has no occasion to be concerned with the distinctions which the Code makes between *inspection* and *examination*, since ASTM activities and documents do not involve the *Inspector* described in the Code Sections. However, no attempt has been made to edit the ASTM documents to conform with Code usage; this should cause no difficulty if the users of this Section recognize that the terms *inspection, testing*, and *examination* in the ASTM documents referenced in Subsection B do not describe duties of the *Inspector* but rather describe the things to be done by the organization's *examination* personnel.

T-180 EVALUATION

The acceptance criteria for the NDE methods in this Section shall be as stated in the referencing Code Section, and where provided in the Articles of this Section. Acceptance criteria in the referencing Code Section shall take precedence.

T-190 RECORDS/DOCUMENTATION

(a) Documentation and records shall be prepared as specified by the referencing Code Section and the applicable requirements of this Section. Examination records shall include the following information as a minimum:

(1) date of the examination

(2) name and/or identity and certification level (if applicable) for personnel performing the examination

(3) identification of the weld, part, or component examined including weld number, serial number, or other identifier

(4) examination method, technique, procedure identification, and revision

(5) results of the examination

(b) Personnel qualification and procedure performance demonstrations performed in compliance with the requirements of T-150(a) or T-150(b) shall be documented as specified by the referencing Code Section.

(c) When documentation requirements for personnel qualification and procedure performance demonstrations performed in compliance with the requirements of T-150(a) or T-150(b) are not specified by the referencing Code Section, the following information shall be recorded as a minimum:

(1) name of organization responsible for preparation and approval of the examination procedure

(2) examination method applied

(3) procedure number or designation

(4) number and date of most recent revision

(5) date of the demonstration

(6) name and/or identity and certification level (if applicable) of personnel performing demonstration

(d) Retention of examination records and related documentation (e.g., radiographs and review forms, ultrasonic scan files, etc.) shall be as specified by the referencing Code Section.

(e) Digital images and reviewing software shall be retained under an appropriate record retention system that is capable of securely storing and retrieving data for the time period specified by the referencing Code Section.

MANDATORY APPENDIX I
GLOSSARY OF TERMS FOR NONDESTRUCTIVE EXAMINATION

I-110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and the definitions of those terms for Section V.

I-120 GENERAL REQUIREMENTS

The terms and definitions provided in this Appendix apply to the nondestructive examination methods and techniques described in Section V. Some terms are identical to those provided in ASTM E1316, while others are Code specific. The terms are grouped by examination method, in the order of the Articles contained in Section V.

(19) I-121 GENERAL TERMS

area of interest: the specific portion of the object that is to be evaluated as defined by the referencing Code Section.

defect: one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable.

discontinuity: a lack of continuity or cohesion; an intentional or unintentional interruption in the physical structure or configuration of a material or component.

evaluation: determination of whether a relevant indication is cause to accept or to reject a material or component.

examination: the process of determining the condition of an area of interest by nondestructive means against established acceptance or rejection criteria.

false indication: an NDE indication that is interpreted to be caused by a condition other than a discontinuity or imperfection.

flaw: an imperfection or discontinuity that may be detectable by nondestructive testing and is not necessarily rejectable.

flaw characterization: the process of quantifying the size, shape, orientation, location, growth, or other properties of a flaw based on NDE response.

footcandle (fc): the illumination on a surface, 1 ft^2 in area, on which is uniformly distributed a flux of 1 lumen (lm). It equals 10.76 lm/m^2.

imperfection: a departure of a quality characteristic from its intended condition.

indication: the response or evidence from a nondestructive examination that requires interpretation to determine relevance.

inspection: the observation of any operation performed on materials and/or components to determine its acceptability in accordance with given criteria.

interpretation: the process of determining whether an indication is nonrelevant or relevant, which may include determining the indication type and/or other data necessary to apply the established evaluation criteria for acceptance or rejection.

limited certification: an accreditation of an individual's qualification to perform some but not all of the operations within a given nondestructive examination method or technique that consists of one or more than one operation, or to perform nondestructive examinations within a limited scope of responsibility.

lux (lx): a unit of illumination equal to the direct illumination on a surface that is everywhere 1 m from a uniform point source of one candle intensity or equal to 1 lm/m^2.

method: the following is a list of nondestructive examination methods and respective abbreviations used within the scope of Section V:

RT — Radiography
UT — Ultrasonics
MT — Magnetic Particle
PT — Liquid Penetrants
VT — Visual
LT — Leak Testing
ET — Electromagnetic (Eddy Current)
AE — Acoustic Emission

nondestructive examination (NDE): the development and application of technical methods to examine materials and/or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, interpret, and evaluate flaws.

nonrelevant indication: an NDE indication that is caused by a condition or type of discontinuity that is not rejectable. False indications are nonrelevant.

operation: a specific phase of a method or technique.

personnel demonstration: when an individual displays an understanding of the examination method and proficiency in conducting the examination, by performing a demonstration examination using the employer's written nondestructive examination procedure.

procedure: an orderly sequence of actions describing how a specific technique shall be applied.

procedure demonstration: when a written procedure is demonstrated, to the satisfaction of the Inspector, by applying the examination method using the employer's written nondestructive examination procedure to display compliance with the requirements of this Section, under

(a) normal examination conditions per T-150(a), or

(b) special conditions as described in T-150(b).

procedure qualification: when a written nondestructive examination procedure is qualified in accordance with the detailed requirements of the referencing Code Section.

reference standard: a material or object for which all relevant chemical and physical characteristics are known and measurable, used as a comparison for, or standardization of, equipment or instruments used for nondestructive testing.

relevant indication: an NDE indication that is caused by a condition or type of discontinuity that requires evaluation.

sensitivity: a measure of the level of response from a discontinuity by a nondestructive examination.

Standard:

(a) a physical reference used as a basis for comparison or calibration.

(b) a concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quality or the establishment of a practice or procedure.

technique: a technique is a specific way of utilizing a particular nondestructive examination (NDE) method.

unprocessed data: the original recorded data prior to any post-examination modification, transformation, or enhancement.

visible light (white light): electromagnetic radiation in the 400-nm to 700-nm (4 000-Å to 7 000-Å) wavelength range.

I-121.1 RT — Radiography.

analog image: an image produced by a continuously variable physical process (for example, exposure of film).

annotate: to provide an explanatory note on the digital image.

back-scattered radiation: radiation which is scattered more than 90 deg with respect to the incident beam, that is, backward in the general direction of the radiation source.

bad pixel: a pixel with performance outside of a specified range; pixels may be dead, overresponding, underresponding, noisy, nonuniform, or nonpersistent.

calibrated line pair test pattern: see *optical line pair test pattern*.

calibrated step wedge film: a radiograph with discrete density steps, which is traceable to a national standard.

cassette: a light-tight container for holding radiographic recording media during exposure, for example, film, with or without intensifying or conversion screens.

cluster kernel pixel (CKP): pixels that do not have five or more good neighborhood pixels.

composite viewing: the viewing of two or more superimposed radiographs from a multiple film exposure.

computed radiography (CR) (photostimulated luminescence method): a two-step radiographic imaging process. First, a storage phosphor imaging plate is exposed to penetrating radiation; second, the luminescence from the plate's photostimulable luminescent phosphor is detected, digitized, and displayed on a monitor.

contrast sensitivity: a measure of the minimum percentage change in an object which produces a perceptible density/ brightness change in the radiological image.

contrast sensitivity (per Mandatory Appendix VI): the size of the smallest detectable change in optical density.

contrast stretch: a function that operates on the grayscale values in an image to increase or decrease image contrast.

data compression: a reduction in the size of a digital data set to a smaller data set.

densitometer: a device for measuring the optical density of radiograph film.

density (film): see *film density*.

density shift: a function that raises or lowers all density/ grayscale values equally such that contrast is maintained within the data set.

designated wire: the specific wire that must be discernible in the radiographic image of a wire-type image quality indicator.

diaphragm: an aperture (opening) in a radiation opaque material that limits the usable beam size of a radiation source.

digital: the representation of data or physical quantities in the form of discrete codes, such as numerical characters, rather than a continuous stream.

digital detector array (DDA): an electronic device that converts ionizing or penetrating radiation into a discrete array of analog signals that are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted on the region of the device.

digital detector system (DDS): a digital imaging system that uses, but is not limited to, a DDA or LDA as the detector.

digital image: an image composed of discrete pixels each of which is characterized by a digitally represented luminance level.

digital image acquisition system: a system of electronic components which, by either directly detecting radiation or converting analog radiation detection information, creates an image of the spatial radiation intensity map comprised of an array of discrete digital intensity values (see *pixel*).

digital radiography (DR): all radiography methods whereby image data is stored in a digital format.

digitize (for radiology): the act of converting an analog image or signal to a digital presentation.

display pixel size: the length and width dimensions of the smallest element of a displayed image.

dynamic range: the range of operation of a device between its upper and lower limits; this range can be given as a ratio (e.g., 100:1) of the maximum signal level capability to its noise level, the number of measurable steps between the upper and lower limits, the number of bits needed to record this number of measurable steps, or the maximum and minimum measurable values.

dynamic range (per Mandatory Appendix VI): the extent of measurable optical density obtained in a single scan.

equivalent IQI sensitivity: that thickness of hole-type IQI, expressed as a percentage of the part thickness, in which $2T$ hole would be visible under the same radiographic conditions.

erasable optical medium: an erasable and rewritable storage medium where the digital data is represented by the degree of reflectivity of the medium recording layer; the data can be altered.

essential hole: the specific hole that must be discernible in the radiographic image of a hole-type IQI.

film density: the quantitative measure of diffuse optical light transmission (optical density, blackening) through a developed film.

$$D = \log\left(I_o/I\right)$$

where

D = optical density
I = light intensity transmitted
I_o = light intensity incident on the film

focal spot: for X-ray generators, that area of the anode (target) of an X-ray tube which emits X-rays when bombarded with electrons.

fog: a general term used to denote any increase in optical density of a processed photographic emulsion caused by anything other than direct action of the image forming radiation and due to one or more of the following:

(a) aging: deterioration, before or after exposure, or both, resulting from a recording medium that has been stored for too long a period of time, or other improper conditions.

(b) base: the minimum uniform density inherent in a processed emulsion without prior exposure.

(c) chemical: resulting from unwanted reactions during chemical processing.

(d) dichroic: characterized by the production of colloidal silver within the developed sensitive layer.

(e) exposure: arising from any unwanted exposure of an emulsion to ionizing radiation or light at any time between manufacture and final fixing.

(f) oxidation: caused by exposure to air during developing.

(g) photographic: arising solely from the properties of an emulsion and the processing conditions, for example, the total effect of inherent fog and chemical fog.

(h) threshold: the minimum uniform density inherent in a processed emulsion without prior exposure.

geometric unsharpness: the penumbral shadow in a radiological image, which is dependent upon

(a) radiation source dimensions
(b) source-to-object distance
(c) object-to-detector distance

image: the digital representation of a target on the reference film used to evaluate both the digitization and display aspects of a film digitization system.

image processing: a method whereby digital image data is transformed through a mathematical function.

image processing system: a system that uses mathematical algorithms to manipulate digital image data.

image quality indicator: as follows:

hole type: a rectangular plaque, made of material radiographically similar to that of the object being radiographed, with small diameter holes ($1T$, $2T$, and $4T$) used to check the image quality of the radiograph.

wire type: a set of small diameter wires, made of material radiographically similar to that of the object being radiographed, used to check the image quality of the radiograph.

image storage system: a system that can store digital image data for future use.

intensifying screen: a material that converts a part of the radiographic energy into light or electrons and that, when in contact with a recording medium during exposure, improves the quality of the radiograph, or reduces the exposure time required to produce a radiograph, or both. Three kinds of screens are in common use.

metal screen: a screen consisting of dense metal (usually lead) or of a dense metal compound (for example, lead oxide) that emits primary electrons when exposed to X-rays or gamma radiation.

fluorescent screen: a screen consisting of a coating of phosphors which fluoresces when exposed to X-rays or gamma radiation.

fluorescent-metallic screen: a screen consisting of a metallic foil (usually lead) coated with a material that fluoresces when exposed to X-rays or gamma radiation. The coated surface is placed next to the film to provide fluorescence; the metal functions as a normal metal screen.

IQI: image quality indicator.

IQI sensitivity: in radiography, the minimum discernible image and the designated hole in the plaque-type, or the designated wire image in the wire-type image quality indicator.

line pair resolution: the number of line pairs per unit distance that are detectable in an image.

line pairs per millimeter: a measure of the spatial resolution of an image conversion device. A line pair test pattern consisting of one or more pairs of equal width, high contrast lines, and spaces is utilized to determine the maximum density of lines and spaces that can be successfully imaged. The value is expressed in line pairs per millimeter.

line pair test pattern: a pattern of one or more pairs of objects with high contrast lines of equal width and equal spacing. The pattern is used with an imaging device to measure spatial resolution.

location marker: a number or letter made of lead (Pb) or other highly radiation attenuative material that is placed on an object to provide traceability between a specific area on the image and the part.

log transform: a function that applies a logarithmic mapping to all density/grayscale values in an image; this operation is often performed when the resulting distribution is normal, or if the resulting relationship with another variable is linear.

luminosity: a measure of emitted light intensity.

magnetic storage medium: a storage medium that uses magnetic properties (magnetic dipoles) to store digital data (for example, a moving drum, disk, or tape or a static core or film).

modulation transfer function (MTF): a measure of spatial resolution as a function of contrast; a plot of these variables (spatial resolution and contrast) yields a curve representing the frequency response of the system.

national standard step tablet: an X-ray film with discrete density steps produced and certified by a nationally recognized standardizing body.

nonerasable optical media (optical disk): a storage media that prevents the erasure or alteration of digital data after it is stored.

optical density: the degree of opacity of a translucent medium (darkening of film) expressed as follows:

$$OD = \log\left(I_o/I\right)$$

where

I = light intensity transmitted through the film
I_O = light intensity incident on the film
OD = optical density

optical density step wedge: a radiographic image of a mechanical step wedge with precise thickness increments and may be used to correlate optical film density to the thickness of material, also known as a step tablet.

penetrameter: no longer used in Article 2; see *image quality indicator*.

photostimulable luminescent phosphor: a phosphor capable of storing a latent radiological image which upon laser stimulation will generate luminescence proportional to the radiation intensity.

pixel: the smallest addressable element in an electronic image.

pixel intensity value: the numeric value of a pixel in a digital image.

pixel size: the length and width of a pixel.

quantification: the act of determining or expressing a quantity (i.e., giving a numerical value to a measurement of something).

radiograph: a visible image viewed for acceptance which is created by penetrating radiation acting on a recording medium; either film on a viewer or electronic images on a monitor.

radiographic examination: a nondestructive method for detecting discontinuities in materials and components using penetrating radiation and recording media to produce an image.

recording media: material capable of capturing or storing, or both, a radiological image in digital or analog form.

reference film: a single industrial radiographic film that encompasses the targets necessary for the evaluation and quantification of the performance characteristics of a film digitization system.

screen: alternative term for *intensifying screen*.

sensitivity: the smallest discernible detail and/or contrast change (e.g., IQI hole or wire) in a radiographic image.

shim: a material, radiographically similar to the object being radiographed, that is placed between a hole-type IQI and the object in order to reduce the radiographic density through the image of the hole-type IQI.

source: a machine or radioactive material that emits penetrating radiation.

source side: that surface of the area of interest being radiographed for evaluation nearest the source of radiation.

spatial linearity: the accuracy to which a digitization system reproduces the physical dimensions of information on the original film [in both the horizontal (along a single scan line) and vertical (from one scan line to another) directions].

spatial resolution: the size of the smallest detectable element of the digitized image.

step wedge: a device with discrete step thickness increments used to obtain an image with discrete density step values.

step wedge calibration film: a processed film with discrete density steps that have been verified by comparison with a national standard step tablet.

step wedge comparison film: a processed film with discrete density steps that have been verified by use of a calibrated densitometer, which is used to determine if production radiographs meet density limits.

system induced artifacts: anomalies that are created by a system during the acquisition, display processing, or storage of a digital image.

target: a physical pattern on a reference film used to evaluate the performance of a film digitization system.

underperforming pixels: underresponding pixels whose gray values are less than 0.6 times the median gray value of an area of a minimum of 21 × 21 pixels. This test is done on an offset corrected image.

WORM (write once read many): a term relating to a type of digital storage media where the data can be stored only once but accessed (nondestructively) many times.

I-121.2 UT — Ultrasonics. (**19**)

acoustic pulse: the duration of time between the start and end of the signal when the amplitude reaches 10% of the maximum amplitude.

adaptive total focusing method (ATFM): an iterative process of the total focusing method (TFM) applied typically to layered media to identify the geometry of the refracting or reflecting interface, or both, that allows the processing of the TFM through such interfaces without the prior knowledge or assumption of the geometry.

alternative reflector: a reflector, other than the specified reflector, whose ultrasonic response has been adjusted to be equal to or greater than the response from the specified reflector at the same sound path in the basic calibration block.

amplitude: the vertical pulse height of a signal, usually base to peak, when indicated by an A-scan presentation.

angle beam: a term used to describe an angle of incidence or refraction other than normal to the surface of the test object, as in angle beam examination, angle beam search unit, angle beam longitudinal waves, and angle beam shear waves.

A-scan: a method of data presentation utilizing a horizontal base line that indicates distance, or time, and a vertical deflection from the base line which indicates amplitude.

attenuation: a factor that describes the decrease in ultrasound intensity with distance; normally expressed in decibel per unit length.

attenuator: a device for altering the amplitude of an ultrasonic indication in known increments, usually decibels.

automated ultrasonic examinations (AUT): a technique of ultrasonic examination performed with equipment and search units that are mechanically mounted and guided, remotely operated, and motor-controlled (driven) without adjustments by the technician. The equipment used to perform the examinations is capable of recording the ultrasonic response data, including the scanning positions, by means of integral encoding devices such that imaging of the acquired data can be performed.

axial direction: direction of sound beam parallel to component's major axis.

back reflection: signal response from the far boundary of the material under examination.

back-wall echo: a specular reflection from the back-wall of the component being examined.

back-wall signal: sound wave that travels between the two transducers with a longitudinal velocity that reflects off the material's back surface.

base line: the time of flight or distance trace (horizontal) across the A-scan CRT display (for no signal condition).

beam spread: a divergence of the ultrasonic beam as the sound travels through a medium.

B-scan (parallel scan): scan that shows the data collected when scanning the transducer pair in the direction of the sound beam transversely across a weld.

B-scan presentation: a means of ultrasonic data presentation which displays a cross section of the specimen indicating the approximate length (as detected per scan) of reflectors and their relative positions.

calibration: correlation of the ultrasonic system response(s) with calibration reflector(s).

calibration reflector: a reflector with a dimensioned surface which is used to provide an accurately reproducible reference level.

circumferential direction: direction of sound beam perpendicular to (cylindrical) component's major axis.

classic full matrix capture (FMC): a subset of elementary FMC in which the set of transmitting elements is identical to the set of receiving elements.

clipping: see *reject*.

compound S-scan: set of focal laws using a fanlike series of beam movements through a defined range of angles and elements. The compound S-scan combines the E-scan and S-scan in a single acquisition group.

computerized imaging: computer processed display or analysis and display of ultrasonic data to provide two or three dimensional surfaces.

contact testing: a technique in which the search unit makes contact directly with the test piece through a thin layer of couplant.

couplant: a substance used between the search unit and examination surface to permit or improve transmission of ultrasonic energy.

CRT: cathode ray tube.

C-scan: an ultrasonic data presentation which provides a plan view of the test object, and discontinuities therein.

damping, search unit: limiting the duration of a signal from a search unit subject to a pulsed input by electrically or mechanically decreasing the amplitude of successive cycles.

decibel (dB): twenty times the base ten logarithm of the ratio of two ultrasonic signal amplitudes, dB = 20 log 10 (amplitude ratio).

diffracted signals: diffracted waves from the upper and lower tips of flaws resulting from the flaws' interaction with the incident sound wave.

diffraction: when a wave front direction has been changed by an obstacle or other inhomogeneity in a medium, other than by reflection or refraction.

display grid density: the spacing at which the total focusing method (TFM) image is displayed.

distance–amplitude correction (DAC) curve: see *distance–amplitude response curve*.

distance–amplitude response curve: a curve showing the relationship between the different distances and the amplitudes of ultrasonic response from targets of equal size in an ultrasonic transmitting medium.

D-scan: an ultrasonic data presentation which provides an end view of the specimen indicating the approximate width (as detected per scan) of reflectors and their relative positions.

D-scan (nonparallel scan): scan that shows the data collected when scanning the transducer pair perpendicular to the direction of the sound beam along a weld.

dual search unit: a search unit containing two elements, one a transmitter, the other a receiver.

dynamic calibration: calibration that is conducted with the search unit in motion, usually at the same speed and direction of the actual test examination.

echo: indication of reflected energy.

effective height: the distance measured from the outside edge of the first to last element used in the focal law.

electric simulator: an electronic device that enables correlation of ultrasonic system response initially obtained employing the basic calibration block.

elementary full matrix capture: a subset of full matrix capture (FMC) in which each transmitting pattern consists of only one active element and each receiving pattern consists of one independent element.

encoded manual ultrasonic examinations (EMUT): a technique of ultrasonic examination performed by hand with the addition of an encoder, and may or may not include a guiding mechanism (i.e., a wheel or string encoder attached to the search unit or wedge).

E-scan (also termed an electronic raster scan): a single focal law multiplexed, across a grouping of active elements, for a constant angle beam stepped along the phased array probe length in defined incremental steps.

examination coverage: two-directional search unit beam coverage, both parallel and perpendicular to the weld axis, of the volume specified by the referencing Code Section. Perpendicularly oriented search unit beams are directed from both sides of the weld, when possible, with the angle(s) selected to be appropriate for the configuration being examined.

examination system: a system that includes the ultrasonic instrument, search unit cable, and search unit.

focal law: a phased array operational file that defines the search unit elements and their time delays, for both the transmitter and receiver function.

fracture mechanics based: a standard for acceptance of a weld based on the categorization of imperfections by type (i.e., surface or subsurface) and their size (i.e., length and through-wall height).

free-run (PA): recording a set of data without moving the search units.

free run (TOFD): taking data, without the movement of the probes (e.g., held stationary), of the lateral wave and back-wall reflection to check system software output.

frequency (inspection): effective ultrasonic wave frequency of the system used to inspect the material.

frequency (pulse repetition): the number of times per second an electro-acoustic search unit is excited by the pulse generator to produce a pulse of ultrasonic energy. This is also called pulse repetition rate.

full matrix capture (FMC): a matrix where the recording (the "capture") of coherent A-scan time-domain signals is carried out using a set of transmit and receive pattern combinations within an aperture of an array, resulting in each cell filled with an A-scan. For example, for an elementary FMC, the examiner would select n elements for the transmit pattern and m elements for the receive pattern, forming a synthetic aperture. The matrix would therefore contain $n \times m$ A-scans, having in total n transmitting elements and m receiving elements.

full matrix capture (FMC) frame: the acquired FMC data structure (not a region) for a specific location within the recorded scan; hence, a scan is made up of multiple frames.

full matrix capture/total focusing method (FMC/TFM): an industry term for an examination technique involving the combination of classic FMC data acquisition and TFM data reconstruction.

grid density: the number of datum points over a specified distance in a specified direction, e.g., 25 points/mm. Grid density may not necessarily be fixed, as the user may prefer a higher density in a specified region.

holography (acoustic): an inspection system using the phase interface between the ultrasonic wave from an object and a reference signal to obtain an image of reflectors in the material under test.

immersion testing: an ultrasonic examination method in which the search unit and the test part are submerged (at least locally) in a fluid, usually water.

indication: that which marks or denotes the presence of a reflector.

initial pulse: the response of the ultrasonic system display to the transmitter pulse (sometimes called main bang).

interface: the boundary between two materials.

lateral wave: a compression wave that travels by the most direct route from the transmitting probe to the receiving probe in a TOFD configuration.

linearity (amplitude): a measure of the proportionality of the amplitude of the signal input to the receiver, and the amplitude of the signal appearing on the display of the ultrasonic instrument or on an auxiliary display.

linearity (time or distance): a measure of the proportionality of the signals appearing on the time or distance axis of the display and the input signals to the receiver from a calibrated time generator or from multiple echoes from a plate of material of known thickness.

linear scanning (also termed line scanning): a single pass scan of the search unit parallel to the weld axis at a fixed stand-off distance.

longitudinal wave: those waves in which the particle motion of the material is essentially in the same direction as the wave propagation.

loss of back reflection: an absence or significant reduction in the amplitude of the indication from the back surface of the part under examination.

manual ultrasonic examinations (MUT): a technique of ultrasonic examination performed with search units that are manipulated by hand without the aid of any mechanical guidance system.

matrix capture (MC): a data object constructed from the recording of coherent A-scan time-domain signals, generally presented in a table-like pattern with two axes, where one axis signifies the transmit pattern index and the other signifies the receive pattern index. A single cell, multiple cells, or all the cells may be populated with an A-scan.

mode: the type of ultrasonic wave propagating in the materials as characterized by the particle motion (for example, longitudinal, transverse, and so forth).

multiple back reflections: in ultrasonic straight beam examination, successive reflections from the back and front surfaces of the material.

noise: any undesired signal (electrical or acoustic) that tends to interfere with the reception, interpretation, or processing of the desired signal.

nonparallel or longitudinal scan: a scan whereby the probe pair motion is perpendicular to the ultrasonic beam (e.g., parallel to the weld axis).

parallel or transverse scan: a scan whereby the probe pair motion is parallel to the ultrasonic beam (e.g., perpendicular to the weld axis).

piezoelectric element: materials which when mechanically deformed, produce electrical charges, and conversely, when intermittently charged, will deform and produce mechanical vibrations.

primary reference response (level): the ultrasonic response from the basic calibration reflector at the specified sound path distance, electronically adjusted to a specified percentage of the full screen height.

probe center spacing (PCS): the distance between the marked exit points of a pair of TOFD probes for a specific application.

pulse: a short wave train of mechanical vibrations.

pulse-echo method: an inspection method in which the presence and position of a reflector are indicated by the echo amplitude and time.

pulse repetition rate: see *frequency (pulse repetition)*.

range: the maximum sound path length that is displayed.

reference block: a block that is used both as a measurement scale and as a means of providing an ultrasonic reflection of known characteristics.

reflector: an interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected.

refraction: the angular change in direction of the ultrasonic beam as it passes obliquely from one medium to another, in which the waves have a different velocity.

reject (suppression): a control for minimizing or eliminating low amplitude signals (electrical or material noise) so that larger signals are emphasized.

resolution: the ability of ultrasonic equipment to give simultaneous, separate indications from discontinuities having nearly the same range and lateral position with respect to the beam axis.

ringing time: the time that the mechanical vibrations of a piezoelectric element continue after the electrical pulse has stopped.

SAFT-UT: Synthetic Aperture Focusing Technique for ultrasonic testing.

scanning: the movement of a search unit relative to the test piece in order to examine a volume of the material.

scanning surface: see *test surface*.

scan plan: a documented examination strategy that provides a standardized and repeatable methodology for weld examinations. The scan plan displays cross-sectional joint geometry, extent of coverage, clad or overlay (if present), heat-affected zone (HAZ) extent, search unit size(s) and frequency(ies), beam plots of all angles used, search unit(s) position in relation to the weld centerline [probe center spacing (PCS) in the case of time of flight diffraction (TOFD)], search unit mechanical fixturing device, and if applicable, zonal coverage overlap.

search unit: an electro-acoustic device used to transmit or receive ultrasonic energy or both. The device generally consists of a nameplate, connector, case, backing, piezoelectric element, and wearface, lens, or wedge.

search unit mechanical fixturing device: the component of an automated or semiautomated scanning apparatus attached to the scanner frame that secures the search unit or search unit array at the spacing and offset distance specified by the scan plan and that provides for consistent contact (for contact techniques) or suitable water path (for immersion techniques).

semiautomated ultrasonic examinations (SAUT): a technique of ultrasonic examination performed with equipment and search units that are mechanically mounted and guided, manually assisted (driven), and which may be manually adjusted by the technician. The equipment used to perform the examinations is capable of recording the ultrasonic response data, including the scanning positions, by means of integral encoding devices such that imaging of the acquired data can be performed.

sensitivity: a measure of the smallest ultrasonic signal which will produce a discernible indication on the display of an ultrasonic system.

shear wave: wave motion in which the particle motion is perpendicular to the direction of propagation.

signal-to-noise ratio: the ratio of the amplitude of an ultrasonic indication to the amplitude of the maximum background noise.

simulation block: a reference block or other item in addition to the basic calibration block that enables correlation of ultrasonic system response initially obtained when using the basic calibration block.

single (fixed angle): a focal law applied to a specific set of active elements for a constant angle beam, emulating a conventional single element probe.

split DAC curves: creating two or more overlapping screen DAC curves with different sensitivity reference level gain settings.

S-scan (also called a Sector, Sectorial, or Azimuthal scan): may refer to either the beam movement or the data display.

(a) beam movement: set of focal laws that provides a fan-like series of beams through a defined range of angles using the same set of elements.

(b) data display: two-dimensional view of all A-scans from a specific set of elements corrected for delay and refracted angle. Volume-corrected S-scan images typically show a pie-shaped display with defects located at their geometrically correct and measurable positions.

static calibration: calibration for examination wherein the search unit is positioned on a calibration block so that the pertinent reflectors can be identified and the instrumentation adjusted accordingly.

straight beam: a vibrating pulse wave train traveling normal to the test surface.

sweep: the uniform and repeated movement of an electron beam across the CRT.

test surface: that surface of a part through which the ultrasonic energy enters or leaves the part.

through transmission technique: a test procedure in which the ultrasonic vibrations are emitted by one search unit and received by another at the opposite surface of the material examined.

time-of-flight: the time it takes for a sound wave to travel from the transmitting transducer to the flaw, and then to the receiving transducer.

TOFD display: a cross-sectional grayscale view of the weld formed by the stacking of the digitized incremental A-scan data. The two types of scans (parallel and nonparallel) are differentiated from each other by calling one a B-scan and the other a D-scan. Currently there is no standardized terminology for these scans and they may be interchanged by various manufacturers (e.g., one calling the scan parallel to the weld axis a B-scan and another a D-scan).

total focusing method (TFM): a method of image reconstruction in which the value of each constituent datum of the image results from focused ultrasound. TFM may also be understood as a broad term encompassing a family of processing techniques for image reconstruction from full matrix capture (FMC). It is possible that equipment of different manufacture may legitimately generate very different TFM images using the same collected data.

total focusing method (TFM) datum point: an individual point calculated within the TFM grid (sometimes referred to as nodes).

total focusing method (TFM) grid/image: a predetermined region of processed data from the matrix capture frame. The grid does not need to be cartesian.

total focusing method (TFM) settings: the information that is required to process a full matrix capture (FMC) data set to reconstruct a TFM image according to the given TFM algorithm.

transducer: an electro-acoustical device for converting electrical energy into acoustical energy and vice versa.

ultrasonic: pertaining to mechanical vibrations having a frequency greater than approximately 20,000 Hz.

vee path: the angle-beam path in materials starting at the search-unit examination surface, through the material to the reflecting surface, continuing to the examination surface in front of the search unit, and reflection back along the same path to the search unit. The path is usually shaped like the letter V.

video presentation: display of the rectified, and usually filtered, r-f signal.

wedge: in ultrasonic angle-beam examination by the contact method, a device used to direct ultrasonic energy into the material at an angle.

workmanship based: a standard for acceptance of a weld based on the characterization of imperfections by type (i.e., crack, incomplete fusion, incomplete penetration, or inclusion) and their size (i.e., length).

I-121.3 PT — Liquid Penetrants.

black light: electromagnetic radiation in the near-ultraviolet range of wavelength (320 nm to 400 nm) (3200 Å to 4000 Å) with peak intensity at 365 nm (3650 Å).

black light intensity: a quantitative expression of ultraviolet irradiance.

bleedout: the action of an entrapped liquid penetrant in surfacing from discontinuities to form indications.

blotting: the action of the developer in soaking up the penetrant from the discontinuity to accelerate bleedout.

clean: free of contaminants.

color contrast penetrant: a highly penetrating liquid incorporating a nonfluorescent dye which produces indications of such intensity that they are readily visible during examination under white light.

contaminant: any foreign substance present on the test surface or in the inspection materials which will adversely affect the performance of liquid penetrant materials.

contrast: the difference in visibility (brightness or coloration) between an indication and the background.

developer: a material that is applied to the test surface to accelerate bleedout and to enhance the contrast of indications.

developer, aqueous: a suspension of developer particles in water.

developer, dry powder: a fine free-flowing powder used as supplied.

developer, nonaqueous: developer particles suspended in a nonaqueous vehicle prior to application.

developing time: the elapsed time between the application of the developer and the examination of the part.

drying time: the time required for a cleaned, rinsed, or wet developed part to dry.

dwell time: the total time that the penetrant or emulsifier is in contact with the test surface, including the time required for application and the drain time.

emulsifier: a liquid that interacts with an oily substance to make it water washable.

family: a complete series of penetrant materials required for the performance of a liquid penetrant testing.

fluorescence: the emission of visible radiation by a substance as a result of, and only during, the absorption of black light radiation.

over-emulsification: excessive emulsifier dwell time which results in the removal of penetrants from some discontinuities.

penetrant: a solution or suspension of dye.

penetrant comparator: an intentionally flawed specimen having separate but adjacent areas for the application of different liquid-penetrant materials so that a direct comparison of their relative effectiveness can be obtained.

NOTE: It can also be used to evaluate liquid-penetrant techniques, liquid-penetrant systems, or test conditions.

penetrant, fluorescent: a penetrant that emits visible radiation when excited by black light.

penetrant, water-washable: a liquid penetrant with a built-in emulsifier.

post-cleaning: the removal of residual liquid penetrant testing materials from the test part after the penetrant examination has been completed.

post emulsification: a penetrant removal technique employing a separate emulsifier.

post-emulsification penetrant: a type of penetrant containing no emulsifier, but which requires a separate emulsifying step to facilitate water rinse removal of the surface penetrant.

precleaning: the removal of surface contaminants from the test part so that they will not interfere with the examination process.

rinse: the process of removing liquid penetrant testing materials from the surface of a test part by means of washing or flooding with another liquid, usually water. The process is also termed wash.

solvent removable penetrant: a type of penetrant used where the excess penetrant is removed from the surface of the part by wiping using a nonaqueous liquid.

solvent remover: a volatile liquid used to remove excess penetrant from the surface being examined.

I-121.4 MT — Magnetic Particle. (19)

ampere turns: the product of the number of turns of a coil and the current in amperes flowing through the coil.

black light: electromagnetic radiation in the near ultraviolet range of wavelength (320 nm to 400 nm) (3200 Å to 4000 Å) with peak intensity at 365 nm (3650 Å).

black light intensity: a quantitative expression of ultraviolet irradiance.

central conductor: a conductor passed through a hollow part and used to produce circular magnetization within the part.

circular magnetization: the magnetization in a part resulting from current passed directly through the part or through a central conductor.

demagnetization: the reduction of residual magnetism to an acceptable level.

direct current (DC): current that flows in only one direction.

dry powder: finely divided ferromagnetic particles suitably selected and prepared for magnetic particle inspection.

full-wave direct current (FWDC): a rectified three-phase alternating current.

full-wave rectified current: when the reverse half of the cycle is turned around to flow in the same direction as the forward half. The result is full-wave rectified current. Three-phase alternating current when full-wave rectified is unidirectional with very little pulsation; only a ripple of varying voltage distinguishes it from straight DC single-phase.

half-wave current (HW): a rectified single-phase alternating current that produces a pulsating unidirectional field.

half-wave rectified alternating current (HWAC): when a single-phase alternating current is rectified in the simplest manner, the reverse of the cycle is blocked out entirely. The result is a pulsating unidirectional current with intervals when no current at all is flowing. This is often referred to as "half-wave" or pulsating direct current.

longitudinal magnetization: a magnetic field wherein the lines of force traverse the part in a direction essentially parallel with its longitudinal axis.

magnetic field: the volume within and surrounding either a magnetized part or a current-carrying conductor wherein a magnetic force is exerted.

magnetic field strength: the measured intensity of a magnetic field at a point, expressed in oersteds or amperes per meter.

magnetic flux: the concept that the magnetic field is flowing along the lines of force suggests that these lines are therefore "flux" lines, and they are called magnetic flux. The strength of the field is defined by the number of flux lines crossing a unit area taken at right angles to the direction of the lines.

magnetic particle examination: see *magnetic particle testing.*

magnetic particle field indicator: an instrument, typically a bi-metal (for example, carbon steel and copper) octagonal disk, containing artificial flaws used to verify the adequacy or direction, or both, of the magnetizing field.

magnetic particles: finely divided ferromagnetic material capable of being individually magnetized and attracted to distortion in a magnetic field.

magnetic particle testing: a nondestructive test method utilizing magnetic leakage fields and suitable indicating materials to disclose surface and near-surface discontinuity indications.

multidirectional magnetization: the alternative application of magnetic fields in different directions during the same time frame.

permanent magnet: a magnet that retains a high degree of magnetization virtually unchanged for a long period of time (characteristic of materials with high retentivity).

prods: hand-held electrodes.

rectified current: by means of a device called a rectifier, which permits current to flow in one direction only. This differs from direct current in that the current value varies from a steady level. This variation may be extreme, as in the case of single-phase half-wave rectified AC (HWAC), or slight, as in the case of three-phase rectified AC.

sensitivity: the degree of capability of a magnetic particle examination technique for indicating surface or near-surface discontinuities in ferromagnetic materials.

suspension: a two-phase system consisting of a finely divided solid dispersed in a liquid.

yoke: a magnet that induces a magnetic field in the area of a part that lies between its poles. Yokes may be permanent magnets or either alternating-current or direct-current electromagnets.

(19) **I-121.5 ET — Electromagnetic (Eddy Current).**

absolute coil: a coil (or coils) that respond(s) to the total detected electric or magnetic properties, or both, of a part or section of the part without comparison to another section of the part or to another part.

array coil topology: a description of the coil arrangement and associated activation pattern within an eddy current array probe.

bobbin coil: for inspection of tubing, a bobbin coil is defined as a circular inside diameter coil wound such that the coil is concentric with a tube during examination.

channel standardization: a data processing method used to provide uniform coil sensitivity to all channels within an eddy current array probe.

detector, n: one or more coils or elements used to sense or measure magnetic field; also known as a receiver.

differential coils: two or more coils electrically connected in series opposition such that any electric or magnetic condition, or both, that is not common to the areas of a specimen being electromagnetically examined will produce an unbalance in the system and thereby yield an indication.

eddy current: an electrical current caused to flow in a conductor by the time or space variation, or both, of an applied magnetic field.

eddy current array (ECA): a nondestructive examination technique that provides the ability to electronically drive multiple eddy current coils, which are placed side by side in the same probe assembly.

eddy current channel: the phase-amplitude signal response resulting from a single instrument input amplifier and individual impedance or transmit–receive coil arrangement.

eddy current testing: a nondestructive testing method in which eddy current flow is induced in the material under examination.

exciter: a device that generates a time-varying electromagnetic field, usually a coil energized with alternating current (ac); also known as a transmitter.

ferromagnetic material: material that can be magnetized or is strongly attracted by a magnetic field.

fill factor (FF):

(a) for encircling coils, the ratio of the test piece cross-sectional area, outside diameter (O.D.), to the effective cross-sectional core area of the primary encircling coil, inside diameter (I.D.), expressed as

$$FF = \frac{(\text{O.D. of test piece})^2}{(\text{I.D. of encircling coil})^2} \times 100 = FF\%$$

(b) for I.D. probes or coils, the ratio of the cross-sectional area of the test probe or coil (O.D.) to the effective cross-sectional core area (I.D.), of the test piece, expressed as

$$FF = \frac{(\text{O.D. of probe or coil})^2}{(\text{I.D. of test piece})^2} \times 100 = FF\%$$

flaw characterization standard: a standard used in addition to the RFT system reference standard, with artificial or service-induced flaws, used for flaw characterization.

frequency: the number of complete cycles per second of the alternating current applied to the probe coil(s) in eddy current examination.

nominal point: a point on the phase-amplitude diagram representing data from nominal tube.

nominal tube: a tube or tube section meeting the tubing manufacturer's specifications, with relevant properties typical of a tube being examined, used for reference in interpretation and evaluation.

nonferromagnetic material: a material that is not magnetizable and hence essentially is not affected by magnetic fields. This would include paramagnetic materials (materials that have a relative permeability slightly greater than unity and that are practically independent of the magnetizing force) and diamagnetic materials (materials whose relative permeability is less than unity).

phase-amplitude diagram: a two-dimensional representation of detector output voltage, with angle representing phase with respect to a reference signal, and radius representing amplitude.

phase angle: the angular equivalent of the time displacement between corresponding points on two sine waves of the same frequency.

probe coil: a small coil or coil assembly that is placed on or near the surface of examination objects.

remote field: as applied to nondestructive testing, the electromagnetic field which has been transmitted through the test object and is observable beyond the direct coupling field of the exciter.

remote field testing (RFT): a nondestructive test method that measures changes in the remote field to detect and characterize discontinuities.

RFT system: the electronic instrumentation, probes, and all associated components and cables required for performing RFT.

RFT system reference standard: a reference standard with specified artificial flaws, used to set up and standardize a remote field system and to indicate flaw detection sensitivity.

sample rate: the rate at which data is digitized for display and recording, in data points per second.

strip chart: a diagram that plots coordinates extracted from points on a phase-amplitude diagram versus time or axial position.

text information: information stored on the recording media to support recorded eddy current data. Examples include tube and steam generator identification, operator's name, date of examination, and results.

unit of data storage: each discrete physical recording medium on which eddy current data and text information are stored. Examples include tape cartridge, floppy disk, etc.

using parties: the supplier and purchaser.

zero point: a point on the phase-amplitude diagram representing zero detector output voltage.

I-121.6 VT — Visual Examination. (19)

artificial flaw: an intentional imperfection placed on the surface of a material to depict a representative flaw condition.

auxiliary lighting: an artificial light source used as a visual aid to improve viewing conditions and visual perception.

candling: see *translucent visual examination*.

direct visual examination: a visual examination technique performed by eye and without any visual aids (excluding light source, mirrors, and/or corrective lenses), e.g., magnifying aids, borescopes, video probes, fiber optics, etc.

enhanced visual examination: a visual examination technique using visual aids to improve the viewing capability.

remote visual examination: a visual examination technique used with visual aids for conditions where the area to be examined is inaccessible for direct visual examination.

surface glare: reflections of artificial light that interfere with visual examination.

translucent laminate: a series of glass reinforced layers, bonded together, and having capabilities of transmitting light.

translucent visual examination: a technique using artificial lighting intensity to permit viewing of translucent laminate thickness variations (also called *candling*).

visual examination: a nondestructive examination method used to evaluate an item by observation, such as the correct assembly, surface conditions, or cleanliness of materials, parts, and components used in the fabrication and construction of ASME Code vessels and hardware.

I-121.7 LT — Leak Testing. (19)

absolute pressure: pressure above the absolute zero corresponding to empty space, that is, local atmospheric pressure plus gauge pressure.

background reading (background signal): in leak testing, the steady or fluctuating output signal of the leak detector caused by the presence of residual tracer gas or other substance to which the detecting element responds.

calibration leak standard (standard leak): a device that permits a tracer gas to be introduced into a leak detector or leak testing system at a known rate to facilitate calibration of the leak detector.

detector probe (sampling probe): in leak testing, a device used to collect tracer gas from an area of the test object and feed it to the leak detector at the reduced pressure required. Also called a sniffing probe.

dew point temperature: that temperature at which the gas in a system would be capable of holding no more water vapor and condensation in the form of dew would occur.

differential pressure: is attained on a system and the time when the test technique is performed to detect leakage or measure leakage rate.

dry bulb temperature: the ambient temperature of the gas in a system.

foreline: a vacuum line between pumps of a multistage vacuum pumping system. A typical example is the vacuum line connecting the discharge port of a high vacuum pump, such as a turbomolecular pump, and the inlet of a rough vacuum pump.

halogen: any element of the family of the elements fluorine, chlorine, bromine, and iodine. Compounds do not fall under the strict definition of halogen. However, for the purpose of Section V, this word provides a convenient descriptive term for halogen-containing compounds. Of significance in halogen leak detection are those which have enough vapor pressure to be useful as tracer gases.

halogen diode detector (halogen leak detector): a leak detector that responds to halogen tracer gases. Also called halogen-sensitive leak detector or halide leak detector.

(a) The copper-flame detector or halide torch consists of a Bunsen burner with flame impinging on a copper plate or screen, and a hose with sampling probe to carry tracer gas to the air intake of the burner.

(b) The alkali-ion diode halogen detector depends on the variation of positive ion emission from a heated platinum anode when halogen molecules enter the sensing element.

helium mass spectrometer (mass spectrometer): an instrument that is capable of separating ionized molecules of different mass to charge ratio and measuring the respective ion currents. The mass spectrometer may be used as a vacuum gauge that relates an output which is proportioned to the partial pressure of a specified gas, as a leak detector sensitive to a particular tracer gas, or as an analytical instrument to determine the percentage composition of a gas mixture. Various types are distinguished by the method of separating the ions. The principal types are as follows:

(a) Dempster (M.S.): The ions are first accelerated by an electric field through a slit, and are then deflected by a magnetic field through 180 deg so as to pass through a second slit.

(b) Bainbridge-Jordan (M.S.): The ions are separated by means of a radial electrostatic field and a magnetic field deflecting the ions through 60 deg so arranged that the dispersion of ions in the electric field is exactly compensated by the dispersion in the magnetic field for a given velocity difference.

(c) Bleakney (M.S.): The ions are separated by crossed electric and magnetic fields. Also called cross fields (M.S.).

(d) Nier (M.S.): A modification of the Dempster (M.S.) in which the magnetic field deflects the ions.

*(e) Time of Flight (M.S.):*The gas is ionized by a pulse-modulated electron beam and each group of ions is accelerated toward the ion collector. Ions of different mass to charge ratios traverse their paths in different times.

(f) Radio-Frequency (M.S.): The ions are accelerated into a radio-frequency analyzer in which ions of a selected mass to charge are accelerated through openings in a series of spaced plates alternately attached across a radio-frequency oscillator. The ions emerge into an electrostatic field which permits only the ions accelerated in the analyzer to reach the collector.

(g) Omegatron (M.S.): The ions are accelerated by the cyclotron principle.

HMSLD: an acronym for helium mass spectrometer leak detector.

hood technique (hood test): an overall test in which an object under vacuum test is enclosed by a hood which is filled with tracer gas so as to subject all parts of the test object to examination at one time. A form of dynamic leak test in which the entire enclosure or a large portion of its external surface is exposed to the tracer gas while the interior is connected to a leak detector with the objective of determining the existence of leakage.

immersion bath: a low surface tension liquid into which a gas containing enclosure is submerged to detect leakage which forms at the site or sites of a leak or leaks.

immersion solution: see *immersion bath*.

inert gas: a gas that resists combining with other substances. Examples are helium, neon, and argon.

instrument calibration: introduction of a known size standard leak into an isolated leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector is capable of indicating for a particular division on the leak indicator scale.

leak: a hole, or void in the wall of an enclosure, capable of passing liquid or gas from one side of the wall to the other under action of pressure or concentration differential existing across the wall, independent of the quantity of fluid flowing.

leakage: the fluid, either liquid or gas, flowing through a leak and expressed in units of mass flow; i.e., pressure and volume per time.

leakage rate: the flow rate of a liquid or gas through a leak at a given temperature as a result of a specified pressure difference across the leak. Standard conditions for gases are 25°C and 100 kPa. Leakage rates are expressed in various units such as pascal cubic meters per second or pascal liters per second.

leak standard (standard leak): a device that permits a tracer gas to be introduced into a leak detector or leak testing system at a known rate to facilitate calibration of the leak detector.

leak testing: comprises procedures for detecting or locating or measuring leakage, or combinations thereof.

mass spectrometer leak detector: a mass spectrometer adjusted to respond only to the tracer gas.

mode lock: a feature of a multiple mode mass spectrometer leak detector that can be used to limit automatic mode changes of the instrument.

multiple mode: with respect to those mass spectrometer leak detectors that, through a change in internal valve alignment, can operate in differing test modes. For example, one test mode may expose the test port and test sample to the foreline port of a turbomolecular pump, and thence to the spectrometer tube. In a more sensitive test mode, the test port and test sample may be exposed to a midstage port of the turbomolecular pump, and thence by a shorter path to the spectrometer tube.

quartz Bourdon tube gage: this high accuracy gage is a servo nulling differential pressure measuring electronic instrument. The pressure transducing element is a one-piece fused quartz Bourdon element.

regular pressure (gage pressure): difference between the absolute pressure and atmospheric pressure.

sensitivity: the size of the smallest leakage rate that can be unambiguously detected by the leak testing instrument, method, or technique being used.

soak time: the elapsed time between when the desired differential pressure is attained on a system and the time when the test technique is performed to detect leakage or measure leakage rate.

standard dead weight tester: a device for hydraulically balancing the pressure on a known high accuracy weight against the reading on a pressure gage for the purpose of calibrating the gage.

system calibration: introduction of a known size standard leak into a test system with a leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector as part of the test system is capable of indicating for a particular division on the leak indicator scale.

test mode: with respect to the internal arrangement of the flow path through a mass spectrometer leak detector from the test port to the mass spectrometer tube.

thermal conductivity detector: a leak detector that responds to differences in the thermal conductivity of a sampled gas and the gas used to zero it (i.e., background atmosphere).

tracer gas: a gas which, passing through a leak, can then be detected by a specific leak detector and thus disclose the presence of a leak. Also called search gas.

vacuum box: a device used to obtain a pressure differential across a weld that cannot be directly pressurized. It contains a large viewing window, special easy seating and sealing gasket, gage, and a valved connection for an air ejector, vacuum pump, or intake manifold.

water vapor: gaseous form of water in a system calibrating the gage.

I-121.8 AE — Acoustic Emission.

acoustic emission (AE): the class of phenomena whereby transient stress/displacement waves are generated by the rapid release of energy from localized sources within a material, or the transient waves so generated.

NOTE: Acoustic emission is the recommended term for general use. Other terms that have been used in AE literature include

(a) stress wave emission
(b) microseismic activity
(c) emission or acoustic emission with other qualifying modifiers

acoustic emission channel: see *channel, acoustic emission.*

acoustic emission count (emission count), N: see *count, acoustic emission.*

acoustic emission count rate: see *count rate, acoustic emission (emission rate or count rate), N.*

acoustic emission event: see *event, acoustic emission.*

acoustic emission event energy: see *energy, acoustic event.*

acoustic emission mechanism or acoustic emission source mechanism: a dynamic process or combination of processes occurring within a material, generating acoustic emission events. AE source mechanisms can be subdivided into several categories: material and mechanical, macroscopic and microscopic, primary and secondary.

NOTE: Examples of macroscopic material AE source mechanisms in metals are incremental crack advancements, plastic deformation development and fracture of inclusions. Friction and impacts are examples of mechanical AE. A crack advancement can be considered a primary AE mechanism while a resulting crack surface friction can be considered as a secondary AE mechanism.

acoustic emission sensor: see *sensor, acoustic emission*.

acoustic emission signal amplitude: see *signal amplitude, acoustic emission*.

acoustic emission signal (emission signal): see *signal, acoustic emission*.

acoustic emission signature (signature): see *signature, acoustic emission*.

acoustic emission transducer: see *sensor, acoustic emission*.

acoustic emission waveguide: see *waveguide, acoustic emission*.

acousto-ultrasonics (AU): a nondestructive examination method that uses induced stress waves to detect and assess diffuse defect states, damage conditions, and variations of mechanical properties of a test structure. The AU method combines aspects of acoustic emission (AE) signal analysis with ultrasonic materials characterization techniques.

adaptive location: source location by iterative use of simulated sources in combination with computed location.

AE activity, n: the presence of acoustic emission during a test.

AE amplitude: see dB_{AE}.

AE monitor: all of the electronic instrumentation and equipment (except sensors and cables) used to detect, analyze, display, and record AE signals.

AE rms, n: the rectified, time averaged AE signal, measured on a linear scale and reported in volts.

AE signal duration: the time between AE signal start and AE signal end.

AE signal end: the recognized termination of an AE signal, usually defined as the last crossing of the threshold by that signal.

AE signal generator: a device which can repeatedly induce a specified transient signal into an AE instrument.

AE signal rise time: the time between AE signal start and the peak amplitude of that AE signal.

AE signal start: the beginning of an AE signal as recognized by the system processor, usually defined by an amplitude excursion exceeding threshold.

array, n: a group of two or more AE sensors positioned on a structure for the purposes of detecting and locating sources. The sources would normally be within the array.

arrival time interval (Δt_{ij}): see *interval, arrival time.*

attenuation, n: the gradual loss of acoustic emission wave energy as a function of distance through absorption, scattering, diffraction, and geometric spreading.

NOTE: Attenuation can be measured as the decrease in AE amplitude or other AE signal parameter per unit distance.

average signal level: the rectified, time averaged AE logarithmic signal, measured on the AE amplitude logarithmic scale and reported in dB_{AE} units (where 0 dB_{AE} refers to 1 μV at the preamplifier input).

burst emission: see *emission, burst*.

channel, acoustic emission: an assembly of a sensor, preamplifier or impedance matching transformer, filters secondary amplifier or other instrumentation as needed, connecting cables, and detector or processor.

NOTE: A channel for examining fiberglass reinforced plastic (FRP) may utilize more than one sensor with associated electronics. Channels may be processed independently or in predetermined groups having similar sensitivity and frequency characteristics.

continuous emission: see *emission, continuous*.

continuous monitoring: the process of monitoring a pressure boundary continuously to detect acoustic emission during plant startup, operation, and shutdown.

count, acoustic emission (emission count), N: the number of times the acoustic emission signal exceeds a preset threshold during any selected portion of a test.

count, event, Ne: the number obtained by counting each discerned acoustic emission event once.

count rate, acoustic emission (emission rate or count rate), N: the time rate at which emission counts occur.

count, ring-down: see *count, acoustic emission*, the preferred term.

couplant: a material used at the structure-to-sensor interface to improve the transmission of acoustic energy across the interface during acoustic emission monitoring.

cumulative (acoustic emission) amplitude distribution, F (V): see *distribution, amplitude, cumulative*.

cumulative (acoustic emission) threshold crossing distribution, $F_t(V)$: see *distribution, threshold crossing, cumulative*.

dB_{AE}: the peak voltage amplitude of the acoustic emission signal waveform expressed by the equation

$$dB_{AE} = 20 \log V/V_{Ref}$$

where V_{Ref} is 1 μV out of the AE sensor crystal.

dB_{AE} (per Article 11): a logarithmic measure of acoustic emission signal amplitude, referenced to 1 μV at the sensor, before amplification.

$$\text{signal peak amplitude } (dB_{AE}) = (dB_{1\,\mu V\,at\,sensor}) = 20 \log_{10}(A_1/A_0)$$

where

A_0 = 1 μV at the sensor (before amplification)
A_1 = peak voltage of the measured acoustic emission signal (also before amplification)

Acoustic Emission Reference Scale

dB_{AE} Value	Voltage at Sensor
0	1 μV
20	10 μV
40	100 μV
60	1 mV
80	10 mV
100	100 mV

NOTE: In the case of sensors with integral preamplifiers, the A_0 reference is before internal amplification.

dB scale: a relative logarithmic scale of signal amplitude defined by dBV = 20 log V_{in}/V_{out}. The reference voltage is defined as 1 V out of the sensor and V is measured amplitude in volts.

dead time: any interval during data acquisition when the instrument or system is unable to accept new data for any reason.

differential (acoustic emission) amplitude distribution, F (V): see *distribution, differential (acoustic emission) amplitude, f*(V).

differential (acoustic emission) threshold crossing distribution, $f_t(V)$: see *distribution, differential (acoustic emission) threshold crossing*.

distribution, amplitude, cumulative (acoustic emission), F (V): the number of acoustic emission events with signals that exceed an arbitrary amplitude as a function of amplitude, V.

distribution, differential (acoustic emission) amplitude, f(V): the number of acoustic emission events with signal amplitudes between amplitudes of V and $V + \Delta V$ as a function of the amplitude V. $f(V)$ is the absolute value of the derivative of the cumulative amplitude distribution, $F(V)$.

distribution, differential (acoustic emission) threshold crossing, $f_t(V)$: the number of times the acoustic emission signal waveform has a peak between thresholds V and $V + \Delta V$ as a function of the threshold V. $f_t(V)$ is the absolute value of the derivative of the cumulative threshold crossing distribution, $F_t(V)$.

distribution, logarithmic (acoustic emission) amplitude, g(V): the number of acoustic emission events with signal amplitudes between V and αV (where α is a constant multiplier) as a function of the amplitude. This is a variant of the differential amplitude distribution, appropriate for logarithmically windowed data.

distribution, threshold crossing, cumulative (acoustic emission), $F_t(V)$: the number of times the acoustic emission signal exceeds an arbitrary threshold as a function of the threshold voltage (V).

dynamic range: the difference, in decibels, between the overload level and the minimum signal level (usually fixed by one or more of the noise levels, low-level distortion, interference, or resolution level) in a system or sensor.

effective velocity, n: velocity calculated on the basis of arrival times and propagation distances determined by artificial AE generation; used for computed location.

electronic waveform generator: a device which can repeatedly induce a transient signal into an acoustic emission processor for the purpose of checking, verifying, and calibrating the instrument.

emission, burst: a qualitative description of an individual emission event resulting in a discrete signal.

emission, continuous: a qualitative description of emission producing a sustained signal as a result of time overlapping and/or successive emission events from one or several sources.

energy, acoustic emission event: the total elastic energy released by an emission event.

energy, acoustic emission signal: the energy contained in an acoustic emission signal, which is evaluated as the integral of the volt-squared function over time.

evaluation threshold: a threshold value used for analysis of the examination data. Data may be recorded with a system examination threshold lower than the evaluation threshold. For analysis purposes, dependence of measured data on the system examination threshold must be taken into consideration.

event, acoustic emission (emission event): an occurrence of a local material change or mechanical action resulting in acoustic emission.

event count (Ne): see *count, event*.

event count rate (Ne): see *rate, event count*.

examination area (examination region): that portion of a structure, or test article, being examined using acoustic emission technology.

felicity effect: the presence of detectable acoustic emission at a fixed predetermined sensitivity level at stress levels below those previously applied.

felicity ratio: the ratio of the load at which acoustic emission is detected, to the previously applied maximum load.

NOTE: The fixed sensitivity level will usually be the same as was used for the previous loading or examination.

first hit location: a zone location method defined by which a channel among a group of channels first detects the signal.

floating threshold: any threshold with amplitude established by a time average measure of the input signal.

hit: the detection and measurement of an AE signal on a channel.

instrumentation dead time: see *dead time, instrumentation*.

interval, arrival time (Δt_{ij}): the time interval between the detected arrivals of an acoustic emission wave at the i-th and j-th sensors of a sensor array.

Kaiser effect: the absence of detectable acoustic emission at a fixed sensitivity level, until previously applied stress levels are exceeded.

NOTE: Whether or not the effect is observed is material specific. The effect usually is not observed in materials containing developing flaws.

limited zone monitoring: the process of monitoring only a specifically defined portion of the pressure boundary by using either the sensor array configuration, controllable instrumentation parameters, or both to limit the area being monitored.

location accuracy, n: a value determined by comparison of the actual position of an AE source (or simulated AE source) to the computed location.

location, cluster, n: a location technique based upon a specified amount of AE activity located within a specified length or area, for example: 5 events within 12 linear inches or 12 square inches.

location, computed, n: a source location method based on algorithmic analysis of the difference in arrival times among sensors.

NOTE: Several approaches to computed location are used, including linear location, planar location, three dimensional location, and adaptive location.

linear location, n: one dimensional source location requiring two or more channels.

planar location, n: two dimensional source location requiring three or more channels.

3D location, n: three dimensional source location requiring five or more channels.

adaptive location, n: source location by iterative use of simulated sources in combination with computed location.

location, continuous AE signal, n: a method of location based on continuous AE signals, as opposed to hit or difference in arrival time location methods.

NOTE: This type of location is commonly used in leak location due to the presence of continuous emission. Some common types of continuous signal location methods include signal attenuation and correlation analysis methods.

signal attenuation-based source location, n: a source location method that relies on the attenuation versus distance phenomenon of AE signals. By monitoring the AE signal magnitudes of the continuous signal at various points along the object, the source can be determined based on the highest magnitude or by interpolation or extrapolation of multiple readings.

correlation-based source location, n: a source location method that compares the changing AE signal levels (usually waveform based amplitude analysis) at two or more points surrounding the source and determines the time displacement of these signals. The time displacement data can be used with conventional hit based location techniques to arrive at a solution for the source site.

location, source, n: any of several methods of evaluating AE data to determine the position on the structure from which the AE originated. Several approaches to source location are used, including zone location, computed location, and continuous location.

location, zone, n: any of several techniques for determining the general region of an acoustic emission source (for example, total AE counts, energy, hits, and so forth).

NOTE: Several approaches to zone location are used, including independent channel zone location, first hit zone location, and arrival sequence zone location.

independent channel zone location, n: a zone location technique that compares the gross amount of activity from each channel.

first-hit zone location, n: a zone location technique that compares only activity from the channel first detecting the AE event.

arrival sequence zone location, n: a zone location technique that compares the order of arrival among sensors.

logarithmic (acoustic emission) amplitude distribution g (V): see *distribution, logarithmic (acoustic emission) amplitude*.

measured area of the rectified signal envelope: a measurement of the area under the envelope of the rectified linear voltage time signal from the sensor.

multichannel source location: a source location technique which relies on stress waves from a single source producing hits at more than one sensor. Position of the source is determined by mathematical algorithms using difference in time of arrival.

overload recovery time: an interval of nonlinear operation of an instrument caused by a signal with amplitude in excess of the instrument's linear operating range.

penetrations: in nuclear applications, the term penetrations refers to step-plugs containing electronic instrumentation cable sections installed through shielding or containment walls to permit passing instrumentation power and information signals through these protective walls without compromising the protective integrity of the wall.

performance check, AE system: see *verification, AE system*.

plant/plant system: the complete pressure boundary system including appurtenances, accessories, and controls that constitute an operational entity.

plant operation: normal operation including plant warm-up, startup, shutdown, and any pressure or other stimuli induced to test the pressure boundary for purposes other than the stimulation of AE sources.

processing capacity: the number of hits that can be processed at the processing speed before the system must interrupt data collection to clear buffers or otherwise prepare for accepting additional data.

processing speed: the sustained rate (hits/sec), as a function of the parameter set and number of active channels, at which AE signals can be continuously processed by a system without interruption for data transport.

rate, event count (Ne): the time rate of the event count.

rearm delay time: see *time, rearm delay*.

ring-down count: see *count, acoustic emission*, the preferred term.

RMS voltage: the root mean square voltage or the rectified, time averaged AE signal, measured on a linear scale and reported in volts.

sensor, acoustic emission: a detection device, generally piezoelectric, that transforms the particle motion produced by an elastic wave into an electrical signal.

sensor array: multiple AE sensors arranged in a geometrical configuration that is designed to provide AE source detection/location for a given plant component or pressure boundary area to be monitored.

signal, acoustic emission (emission signal): an electrical signal obtained by detection of one or more acoustic emission events.

signal amplitude, acoustic emission: the peak voltage of the largest excursion attained by the signal waveform from an emission event.

signal overload level: that level above which operation ceases to be satisfactory as a result of signal distortion, overheating, or damage.

signal overload point: the maximum input signal amplitude at which the ratio of output to input is observed to remain within a prescribed linear operating range.

signal strength: the measured area of the rectified AE signal with units proportional to volt-sec.

NOTE: The proportionality constant is specified by the AE instrument manufacturer.

signature, acoustic emission (signature): a characteristic set of reproducible attributes of acoustic emission signals associated with a specific test article as observed with a particular instrumentation system under specified test conditions.

simulated AE source: a device which can repeatedly induce a transient elastic stress wave into the structure.

stimulation: the application of a stimulus such as force, pressure, heat, and so forth, to a test article to cause activation of acoustic emission sources.

system examination threshold: the electronic instrument threshold (see *evaluation threshold*) which data will be detected.

threshold of detectability: a peak amplitude measurement used for cross calibration of instrumentation from different vendors.

transducers, acoustic emission: see *sensor, acoustic emission*.

verification, AE system (performance check, AE system): the process of testing an AE system to assure conformance to a specified level of performance or measurement accuracy. (This is usually carried out prior to, during, and/or after an AE examination with the AE system connected to the examination object, using a simulated or artificial acoustic emission source.)

voltage threshold: a voltage level on an electronic comparator such that signals with amplitudes larger than this level will be recognized. The voltage threshold may be user adjustable, fixed, or automatic floating.

waveguide, acoustic emission: a device that couples elastic energy from a structure or other test object to a remotely mounted sensor during AE monitoring. An example of an acoustic emission waveguide would be a solid wire of rod that is coupled at one end to a monitored structure, and to a sensor at the other end.

zone: the area surrounding a sensor from which AE sources can be detected.

zone location: a method of locating the approximate source of emission.

I-121.9 Examination System Qualification.

blind demonstration: a performance demonstration, where the examiner is presented with both flawed and unflawed specimens which are visually indistinguishable, with the objective of proving the capability of an examination system to correctly detect and size flaw locations.

detection: when a specimen or grading unit is correctly interpreted as being flawed.

essential variables: a change in the examination system, which will affect the system's ability to perform in a satisfactory manner.

examination system: the personnel, procedures, and equipment collectively applied by a given examination technique to evaluate the flaw characteristics of an object of interest.

false call: when a specimen or grading unit is incorrectly interpreted as being flawed or unflawed.

false call probability (FCP): the percentage resulting from dividing the number of false calls by the number of specimens or grading units examined.

grading unit: a prepared specimen, or designated interval (e.g., length) within a specimen, having known flaw characteristics, which is used to evaluate the performance of an examination system through demonstration.

level of rigor: the level of confidence to which a given examination system must be demonstrated, based upon factors such as user needs, damage mechanism, and level of risk. There are three levels of rigor: low, intermediate, and high (see T-1424).

non-blind demonstration: a performance demonstration where the examiner is presented with test pieces containing clearly identifiable flaw locations of known sizes, with the objective of proving the capability of an examination system to correctly detect and size flaw locations.

nonessential variables: a change in the examination system, which will not affect the system's ability to perform in a satisfactory manner.

performance demonstration: a demonstration of the capabilities of an examination system to accurately evaluate a specimen with known flaw characteristics in an environment simulating field conditions.

probability of detection (POD): the percentage resulting from dividing the number of detections by the number of flawed specimens or grading units examined. POD indicates the probability that an examination system will detect a given flaw.

qualification: successful documentation of an examination system's ability to demonstrate established qualification objectives at the required level of rigor, in compliance with the requirements of Article 14.

I-121.10 APR — Acoustic Pulse Reflectometry.

functional test: the functional test of an APR system is the act of examining the reference tubes and creating a report, then verifying that the results are within the tolerance specified by the standard.

noise level: the amplitude of nonrelevant signals at each point along the tube, measured on a random group of more than 30 tubes. It is used to determine the threshold of detectability at each point along the tubes.

signal-to-noise ratio: the ratio between the amplitude of the transmitted pulse and the maximum nonrelevant indication amplitude (remaining) after reflections of the initial pulse have decreased below detection.

reference tubes/reference specimens: a set of tubes with a variety of known, manufactured flaws at known locations and sizes. By inspecting these tubes and evaluating the results, it is possible to verify that the APR equipment is working properly.

I-121.11 GWT — Guided Wave Examination.

absolute calibration: setting of the gain in the system from a flange or pipe open in the test range to be a 100% reflector. In most field applications there are no flanges or pipe open ends in the test range; therefore, a calibration of the system is obtained using multiple reflections from welds in the test range that are assumed to be approximately 20% reflectors to calculate the DAC and TCG amplitudes.

anomaly: an unexamined indication in the examination result that could be from the pipe material, coatings, soil, or examination conditions. See also *imperfection* and *defect.*

basic piping: straight piping (including up to one elbow) filled with nonattenuative fluid that may be painted or protected with a nonattenuative coating (e.g., fusion bonded epoxy or a non-bonded insulation such as mineral wool) and constructed of a single pipe size and schedules, fully accessible at the test location, jointed by girth welds, and supported by simple contact supports.

bend: a physical configuration that changes pipeline direction. A bend can be classified according to the centerline radius of the bend as a ratio to the nominal pipe diameter.

A $1^1/_2D$ bend would have a centerline radius of $1^1/_2$ times the nominal pipe diameter. A 3*D* bend would have a centerline radius of 3 times the nominal pipe diameter.

call level: amplitude threshold set to identify reflection signals that need to be assessed. It represents a threshold of a particular value of reflection coefficient at any location along the pipe, and so may be used to set a desired sensitivity threshold according to defect size.

cross-sectional change (CSC): commonly refers to the percentage change in cross-sectional area of the pipe wall (increase or decrease such as a weld or wall loss).

dead zone: the length of pipe immediately beneath and adjacent to the GWT sensor that cannot be examined because the transmitting signals have saturated the sensor(s). The length of the dead zone is related to the excitation frequency and the sound velocity in the material.

detection threshold: minimum amplitude level of signal, below which it is not possible to assess signals. In GWT this is set according to the amplitude of the background noise.

distance–amplitude correction (DAC): a DAC curve represents the attenuation of the signal over the distance of the examination region.

examination range: the distance from the GWT sensor for which reflected signals are recorded.

guided wave examination (GWT): an NDE method for assessing lengths of pipe and other components for wall loss, caused by either internal/external corrosion or erosion, gouges, and cracking. Typically a sensor is coupled to the external surface of the pipe and to create a wave that is guided along the wall of the pipe. These guided waves propagate down the pipe and reflect back to the sensor by changes in cross-sectional area of the pipe. The reflected signals are acquired, processed, and displayed in a distance versus amplitude plot.

permissible examination range: the maximum distance from the GWT sensor within which the signal amplitude and quality are sufficient to allow examination to be performed.

reference amplitude: the amplitude of the outgoing guided wave signal, used as the reference for other signal amplitudes and thresholds and the basis for the DAC curves or TCG.

sensor: the GWT device consisting of either piezoelectric or magnetostrictive sensor(s) wrapped around the outside diameter of the pipe being examined.

test range: the length of piping that can be examined from one sensor location.

time-controlled gain or time-corrected gain (TCG): gain added to the signal as a function of time equivalent distance from the initial pulse used to normalize the signal over time to compensate for attenuation.

I-130 UT — ULTRASONICS

automated scanner: automated scanners are fully mechanized, and, after being attached to the component, maintain an index and offset position of the search unit and are manipulated by using an independent motor controller without being handled during operation.

manual scanning: a technique of ultrasonic examination performed with search units that are manipulated by hand, and without data collection.

nonautomated scanner: nonautomated scanners are operated without a mechanical means of holding an index or search unit offset position. Manual scanners are propelled manually by the operator and have no means of holding or maintaining probe position once released.

semiautomated scanner: semiautomated scanners are manually adjustable, have mechanical means to maintain an index of the search unit while maintaining the search unit offset position, but must still be propelled manually by the operator. This scanner does have mechanical means to retain its position while attached to the component once released by the operator.

MANDATORY APPENDIX II SUPPLEMENTAL PERSONNEL QUALIFICATION REQUIREMENTS FOR NDE CERTIFICATION

(19) II-110 SCOPE

This Appendix provides the additional personnel qualification requirements that are mandated by Article 1, T-120(g), and which are to be included in the employer's written practice for NDE personnel certification, when any of the following techniques are used by the employer: computed radiography (CR), digital radiography (DR), phased array ultrasonic (PAUT), ultrasonic time of flight diffraction (TOFD), and ultrasonic full matrix capture (FMC).

II-120 GENERAL REQUIREMENTS

The requirements of Article 1 and this Mandatory Appendix, when applicable, shall be included in the employer's written practice.

(19) II-121 LEVEL I AND LEVEL II TRAINING AND EXPERIENCE REQUIREMENTS

The following tables shall be used for determining the minimum hours for personnel without prior qualification in film; CR or DR techniques in radiography; and PAUT, TOFD, and FMC techniques in ultrasonics to be included in the employer's written practice. See Tables II-121-1 and II-121-2.

For the CR and DR techniques, personnel shall first meet the training and experience requirements in Table II-121-1 for a Level I in that technique as a prerequisite for being eligible for qualification as a Level II in that technique. See Table II-121-1, General Notes for modifications to the number of training and experience hours required.

For TOFD, PAUT, and FMC, see the prerequisite requirements in Table II-121-2.

II-122 LEVEL I AND LEVEL II EXAMINATIONS

II-122.1 In addition to the written examinations specified in Table II-122.1, all CR and DR technique qualifications shall include practical examinations consisting of, as a minimum

(a) Level I practical examinations shall require five test specimens, which cover multiple technique variations and setup parameters. These shall include both single/double wall exposure and single/double wall viewing.

(b) Level II practical examinations shall require five test specimens, which shall include varying thickness, diameter, and exposure techniques, and each specimen shall contain at least one discontinuity.

(c) The employer's written practice shall define the grading criteria for all written and practical examinations.

II-122.2 In addition to the written examinations specified in Table II-122.2, all ultrasonic technique certifications shall include practical examinations consisting of, as a minimum

(a) Level II practical examinations shall require at least two test specimens, with each specimen containing a minimum of two discontinuities.

(b) The employer's written practice shall define the grading criteria for all written and practical examinations.

II-123 LEVEL III REQUIREMENTS

Level III personnel shall be responsible for the training and qualification of individuals in the NDE techniques described in this Mandatory Appendix. As a minimum, the requirements of Level III personnel shall include each of the following:

(a) hold a current Level III certification in the Method

(b) meet the Level II requirements per II-121 (training and experience) and II-122 (examinations) in the technique

(c) have documented evidence in the preparation of NDE procedures to codes, standards, or specifications relating to the technique

(d) demonstrate proficiency in the evaluation of test results in the technique

A Level III who fulfills the above requirements may perform examinations in the applicable technique.

II-124 TRAINING OUTLINES

II-124.1 Computed Radiography (CR) Topical Training Outlines. Topical training outlines appropriate for the training of Level I and Level II personnel in computed radiography may be found in ANSI/ASNT CP-105 (2016 edition)[3] and should be used as a minimum.

II-124.2 Digital Radiography (DR) Topical Training Outlines. Topical training outlines appropriate for the training of Level I and Level II personnel in digital radiography may be found in ANSI/ASNT CP-105 (2016 edition)[3] and should be used as a minimum. For individuals holding a valid Level I or Level II film certification, the "Basic Radiography Physics" segment of the topical outlines referenced in II-124.1 and II-124.2 need not be repeated, as described in the employer's written practice.

II-124.3 Phased Array UT. Topical training outlines appropriate for the training of Level II personnel can be found in ANSI/ASNT CP-105 (2016 edition)[3] and should be used as a minimum.

II-124.4 Time of Flight Diffraction (TOFD). Topical training outlines appropriate for the training of Level II personnel can be found in ANSI/ASNT CP-105 (2016 edition)[3] and should be used as a minimum.

II-124.5 Full Matrix Capture (FMC). Topical training outlines appropriate for the training of Level II personnel can be found in Supplement A of this Appendix and should be used as a minimum. (19)

(19)

Table II-121-1
Initial Training and Experience Requirements for CR and DR Techniques

Examination Method	NDE Level	Technique	Training Hours	Experience: Minimum Hours in Technique	Experience: Total NDE Hours
Radiography	I	CR	40	210	400
	II	CR	40	630	1,200
Radiography	I	DR	40	210	400
	II	DR	40	630	1,200

GENERAL NOTES:

(a) For individuals currently certified in a radiography technique (e.g., film) and a full-course format was used to meet the initial qualifications in that technique, the minimum additional training hours to qualify in another technique at the same level shall be
  (1) Level I, 24 hr
  (2) Level II, 40 hr

  as defined in the employer's written practice.

(b) In addition to the training specified in Table II-121-1, a minimum 16 hr of manufacturer-specific hardware/software training shall also be required for each system/software to be used. The employer's written practice shall describe the means by which the examiner's qualification shall be determined.

(c) For individuals currently certified in a radiography technique (e.g., film) and a full-course format was used to meet the initial qualifications in that technique, the minimum additional experience to qualify in another technique at the same level shall be
  (1) Level I, 105 hr
  (2) Level II, 320 hr

  as defined in the employer's written practice.

(d) For Individuals currently certified as a Level II in a radiography technique (e. g., film), where a full-course format was used to meet the initial qualifications in that technique, who are seeking a Level II certification in another technique but have not completed the additional training hours specified in (a) above, the following minimum requirements shall be met for certification in each additional technique:
  (1) 24 hr of technique-specific training
  (2) 16 hr of manufacturer-specific hardware/software training for each system/software to be used
  (3) an increase in practical examination test specimens required in II-122.1(b), from five to ten, each specimen containing at least one discontinuity

(e) For individuals not currently certified in a radiography technique who are pursuing qualification directly as a Level II in CR or DR, the minimum required training and experience hours in the technique shall consist of at least the sum of the stated Level I and Level II hours in the technique.

(19)

Table II-121-2
Additional Training and Experience Requirements for PAUT, TOFD, and FMC Ultrasonic Techniques

Examination Method	NDE Level	Technique	Training Hours	Experience: Minimum Hours in Technique	Experience: Total NDE Hours
Ultrasonic	II	PAUT	80	320	UT Level I and Level II training and experience required as a prerequisite [Note (1)], [Note (2)]
Ultrasonic	II	TOFD	40	320	
Ultrasonic	II	FMC	80	320	

NOTES:
(1) Level II personnel holding a current Ultrasonic method certification are eligible for certification in the PAUT, TOFD, and FMC techniques.
(2) In addition to the training specified in Table II-121-2, supplemental specific hardware and software training shall be required for automated or semiautomated technique applications. The employer's written practice shall fully describe the nature and extent of the additional training required for each specific acquisition or analysis software and instrument/system used. The employer's written practice shall also describe the means by which the examiner's qualification will be determined for automated and semiautomated techniques.

Table II-122.1
Minimum CR and DR Examination Questions

Technique	General		Specific	
	Level I	Level II	Level I	Level II
CR	40	40	30	30
DR	40	40	30	30

(19)

Table II-122.2
Minimum Ultrasonic Technique Examination Questions

Technique	Level II: General	Level II: Specific
PAUT	40	30
TOFD	40	30
FMC	40	30

(19)

MANDATORY APPENDIX II SUPPLEMENT A

II-A-110 TRAINING OUTLINE FOR LEVEL II PERSONNEL

(a) Overview
(1) Introduction
(2) FMC terminology
(3) History
(4) Ultrasonic theory
(-a) Beam divergence
(-b) Wavelength
(5) Overview of PAUT
(b) Basics of FMC data collection
(c) Equipment
(1) Computer-based system
(2) Processors and throughput
(3) Block diagram showing basic internal components
(4) Portable versus full computer-based systems
(d) Probe
(1) Review of arrays
(-a) Types and configurations
(-b) Effects of pitch and element size relevant to sound transmission
(-c) Aperture size and effects
(2) Probe selection
(3) Dead element check
(e) Essential variables
(f) Scan plan
(1) Major components of a scan plan
(2) Paths
(g) Calibration
(1) Single probe
(2) Tandem probe
(3) Reflectors versus paths
(4) Delay and velocity
(5) TCG
(h) FMC characteristics
(1) Signal characteristics
(2) Scale factor for FMC
(3) FMC data size
(4) Different FMC techniques
(5) FMC versus other data collection
(6) How to use FMC data
(7) Typical FMC data explained
(i) TFM characteristics
(1) Signal characteristics
(2) TFM frame parameters and FMC
(3) TFM and delay laws
(4) Focusing capability
(5) Coverage capability
(6) Impact of frame parameters on amplitude
(7) Adaptive algorithms
(j) Examination
(1) Types of equipment
(-a) Fully automated
(-b) Semiautomated
(-c) Manual
(2) Advantages and disadvantages of each equipment type
(k) Evaluation
(1) Display and display settings
(-a) Imaging
(-b) 3D
(2) Flaw characterization
(3) Flaw dimensioning
(4) Software tools
(5) Image artifacts and saturation
(l) Documentation
(1) Images
(2) Equipment settings
(3) Plotting
(4) Onboard reporting and requirements
(m) Amplitude
(1) Amplitude fidelity
(2) Amplitude subject to resolution
(3) Amplitude and interface/dead zones
(n) Use cases
(1) Weld examinations
(-a) Examination volume
(-b) Impact of geometry
(-c) Material type
(-d) Material thickness
(-e) Probe considerations
(-f) Review typical welding defects and responses
(2) Corrosion examinations
(-a) Advantages and disadvantages
(-b) Probe considerations

(3) Other examples

(-a) Aluminum

(-b) Composites

(-c) Effects of probe frequency and wavelength

(-d) Manufacturing processes and defects

(-e) Types of welding processes

(-f) Historical processes and defects

(o) Procedures and requirements

(1) Codes and standards specific

(2) Customized specific applications

(19)

MANDATORY APPENDIX III EXCEPTIONS AND ADDITIONAL REQUIREMENTS FOR USE OF ASNT SNT-TC-1A 2016 EDITION

Where ASNT SNT-TC-1A 2016 Edition has used the verb "should" throughout the document to emphasize the recommendation presented, Section V has modified many of the "should" statements to designate minimum requirements when SNT-TC-1A is utilized as the basis for the required Written Practice for Section V compliance. Replacing Section V "shall" statements with "should" statements is not allowed.

The following are exceptions, modifications, and additions to SNT-TC-1A 2016 Edition:

1.0 As described in SNT-TC-1A paragraph 1.0 Scope, and subparagraph 1.4

1.1 Paragraph 1.4 when developing a written practice as required in ASME Section V, the employer shall review and include the detailed recommendations presented in SNT-TC-1A–2016 and ASME Section V including this Mandatory Appendix. Modifications that reduce or eliminate basic provisions of the program such as training, experience, testing, and recertification shall not be allowed.

2.0 As described in SNT-TC-1A paragraph 2.0 Definitions and subparagraph 2.1.9.

2.1 Paragraph 2.1.9 Grading units are unflawed or flawed and the percentage of flawed/unflawed grading units required shall be approved by the NDE Level III.

3.0 As described in SNT-TC-1A paragraph 3.0 Nondestructive Testing Methods subparagraph 3.1.

3.1 Paragraph 3.1 Qualifications and certifications of NDE personnel in accordance with ASME Section V are applicable to the following methods:

Acoustic Emission Testing
Electromagnetic Testing
Guided Wave Testing
Leak Testing
Liquid Penetrant Testing
Magnetic Particle Testing
Radiographic TestingVisual Testing
Ultrasonic Testing

4.0 As described in SNT-TC-1A paragraph 4.0 Levels of Qualification, and subparagraphs 4.2, and 4.3;

4.1 Paragraph 4.2 while in the process of being initially trained, qualified, and certified, an individual should be considered a trainee. A trainee shall work with a certified individual. The trainee shall not independently conduct, interpret, evaluate, or report the results of any nondestructive examination.

4.2 Paragraph 4.3.1 an NDE Level I individual shall have sufficient technical knowledge and skills to be qualified to properly perform specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDE Level I shall receive the necessary instruction and supervision from a certified NDE Level II or III individual.

4.3 Paragraph 4.3.2 an NDE Level II individual shall have sufficient technical knowledge and skills to be qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications. The NDE Level II shall be thoroughly familiar with the scope and limitations of the methods for which qualified and shall exercise assigned responsibility for on-the-job training and guidance of trainees and NDE Level I personnel. The NDE Level II shall be able to organize and report the results of NDE activities.

4.4 Paragraph 4.3.3 an NDE Level III individual shall have sufficient technical knowledge and skills to develop, qualify, and approve procedures, establish and approve techniques, interpret codes, standards, specifications, and procedures; and designate the NDE methods, techniques, and procedures to be used. The NDE Level III shall be responsible for the NDE operations for which qualified and assigned and shall be capable of interpreting and evaluating results in terms of existing codes, standards, and specifications. The NDE Level III shall have sufficient practical background in applicable materials, fabrication, and product technology to establish techniques and to assist in establishing acceptance criteria when none are otherwise available. The NDE Level III shall have general familiarity with other appropriate NDE methods, as demonstrated by a Level III Basic examination or other means. The NDE Level III, in the methods in which certified, shall have sufficient technical knowledge and skills to be capable of training and examining NDE Level I, II, and III personnel for certification in those methods.

5.0 As described in SNT-TC-1A paragraph 5.0 Written Practice, and subparagraphs 5.2, 5.3, and 5.4;

5.1 Paragraph 5.2 The written practice shall describe responsibility of each level of certification for determining the acceptability of materials or components in accordance with ASME Section V, and the referencing Codes, Standards, and documents.

5.2 Paragraph 5.3 the written practice shall describe the training, experience, and examination requirements for each level of certification by method and technique.

5.3 Paragraph 5.4 the written practice shall identify NDE techniques within each method applicable to the written practice.

6.0 As described in SNT-TC-1A paragraph 6.0 Education, Training, and Experience Requirements for Initial Qualification, and subparagraphs 6.1, 6.2, 6.3, 6.3.1, and Notes for Table 6.3.1A;

6.1 Paragraph 6.1 candidates for certification in NDE shall have sufficient education, training, and experience to ensure qualification in those NDE methods in which they are being considered for certification. Documentation of prior certification may be used as evidence of qualification for comparable levels of certification provided it has been verified by an NDE Level III.

6.2 Paragraph 6.2 documented training or experience gained in positions and activities comparable to those of Levels I, II, and III prior to establishment of the written practice may be considered when satisfying the criteria for education, training, and experience, provided the information has been verified by an NDE Level III.

6.3 Paragraph 6.3 To be considered for certification, a candidate shall satisfy one of the following criteria for the applicable NDE level:

6.3.1 NDE Level I and II Limited certifications shall apply to individuals who do not meet the full training and experience specified in SNT-TC-1A, Table 6.3.1A. Limited certifications shall be approved by an NDE Level III and documented in certification records.

6.4 Notes for Table 6.3.1A of SNT-TC-1A

6.4.1 Note 2.0 for NDE Level III certification, experience shall consist of the sum of hours for NDE Level I and Level II, plus the additional time in Table 6.3.1B as applicable. The formal training shall consist of NDE Level I and Level II training including additional time required by ASME Section V, the referencing Code, Standards, Specifications, or controlling documents.

6.4.2 Note 7.0 for an individual currently certified in a Radiography technique and a full course format was used to meet the initial qualifications in that technique, also see ASME Section V, Article 1 Mandatory Appendix II for requirements.

6.4.3 Note 10.0 for TOFD and PAUT see ASME Section V, Article 1 Mandatory Appendix II for requirements.

6.5 Note for Table 6.3.1B, review of 1000 radiographs are not required, the practical examination shall consist of a sufficient number of radiographs to demonstrate satisfactory performance to the certifying Level III or sufficient documented experience as deemed appropriate by the certifying Level III.

7.0 As described in SNT-TC-1A paragraph 7.0 Training Programs and subparagraphs 7.1 and 7.2;

7.1 Paragraph 7.1 Personnel being considered for initial certification shall complete sufficient organized training to become thoroughly familiar with principles and practices of the specified NDE method related to the level of certification desired and applicable to the processes used and products to be examined. The organized training may include instructor-led training, personalized instruction, virtual instructor-led training, computer-based training, or web-based training. Computer-based training and web-based training shall track hours and content of training with student examinations. The organized training shall ensure the student is thoroughly familiar with principles and practices of the specified NDE method, as applicable to processes used and the products to be examined. All training programs shall be approved by an NDE Level III. Hours shall not be credited for "self-study" scenarios.

7.2 The training program shall include sufficient examinations to ensure understanding of the necessary information.

8.0 As described in SNT-TC-1A paragraph 8.0 Examinations and subparagraphs 8.1.1, 8.1.2, 8.1.2.1, 8.1.3, 8.1.5, 8.2.1, 8.2.2, 8.2.3, 8.3.1, 8.3.2, 8.3.4, 8.4.1, 8.4.2, 8.4.3, 8.4.4, 8.5.1, 8.5.2, 8.5.2.1, 8.5.2.2, 8.5.4, 8.5.5, 8.5.6, 8.6, 8.7.3.2, 8.7.4, and 8.7.5;

8.1 Paragraph 8.1.1 Qualification examination questions shall be approved by an NDE Level III responsible for the examinations.

8.2 Paragraph 8.1.2 an NDE Level III shall be responsible for administration and grading of General, Specific, and Practical examinations for Level I, and Level II personnel, as well as Basic, Method, Specific, Practical, and Demonstration examinations for Level III personnel. Administration and grading of examinations may be delegated to qualified representatives of the NDE Level III and so recorded. A qualified representative of the employer may perform the actual administration and grading of Level III basic and method examinations. Approved Outside Agencies may also be utilized for examination activities provided the written practice addresses use of outside agencies.

8.3 Paragraph 8.1.2.1 to be designated as a qualified representative of the NDE Level III for the administration and grading of NDE Level I and Level II qualification examinations, the designee shall have documented, appropriate instruction in proper administration and grading of examinations prior to conducting and grading qualification examinations for NDE personnel. Additionally, practical examinations shall be administered by an individual certified in the method as Level II or III

8.4 Paragraph 8.1.3 NDE Level I, II, and III written examinations shall be closed-book except that necessary data, such as graphs, tables, specifications, procedures, codes, etc., may be provided. Questions utilizing such reference materials should require an understanding of the information rather than merely locating the appropriate answer.

8.5 Paragraph 8.1.4 a composite grade should be determined by simple averaging of the results of the required examinations.

8.6 Paragraph 8.1.5 examinations administered by the employer for qualification shall result in a passing composite grade of at least 80 percent, with no individual examination having a passing grade less than 70 percent. The Practical examination shall have a passing grade of at least 80 percent.

8.7 Paragraph 8.2.1 Near-Vision Acuity examination shall be administered annually. The examination shall ensure natural or corrected near-distance acuity in at least one eye such that the applicant is capable of reading a minimum of Jaeger Number 1 or equivalent type and size letter at the distance designated on the chart but not less than 12 in. (30.5 cm) on a standard Jaeger test chart or an equivalent Ortho-Rater or similar test pattern.

8.8 Paragraph 8.2.2 Color Contrast Differentiation shall be administered annually. The examination shall demonstrate the capability of distinguishing and differentiating contrast among colors or shades of gray used in the method as determined by the employer.

8.9 Paragraph 8.2.3 is not allowed, re-examination requirements are above.

8.10 Paragraph 8.3.1 the General examination shall address the basic principles of the method.

8.11 Paragraph 8.3.2 the examinations shall contain questions covering the applicable method to the degree required by the written practice.

8.12 Paragraph 8.3.4 the minimum number of questions that shall be given are as shown in Table 8.3.4 except for CR, DR Radiography and TOFD, PAUT ultrasonics are defined in Mandatory Appendix II.

8.13 Paragraph 8.4.1 Specific examination shall address equipment, operating procedures, and NDE techniques that may encounter during specific assignments as required by the written practice.

8.14 Paragraph 8.4.2 Specific examinations shall cover the specifications or codes and acceptance criteria used in the employer's NDE procedures.
8.15 Paragraph 8.4.3 minimum number of questions that shall be given as shown in Table 8.3.4.
8.16 Paragraph 8.4.4 shall not be allowed.
8.17 Paragraph 8.5.1 the candidate shall demonstrate familiarity with and ability to operate necessary NDE equipment, record, and analyze the resultant information to the degree required.
8.18 Paragraph 8.5.2 numbers of flawed specimens for CR, DR Radiography, and TOFD, PAUT Ultrasonics shall be in accordance with Mandatory Appendix II. Other NDE methods shall require one specimen for each technique practical demonstration and at least two for each method.
8.19 Paragraph 8.5.2.1 shall not be used as requirements are addressed in Mandatory Appendix II.
8.20 Paragraph 8.5.2.2 for Film Interpretation Limited Certification, the practical examination shall consist of a sufficient number of radiographs to demonstrate satisfactory performance to the satisfaction of the certifying Level III or sufficient documented experience.
8.21 Paragraph 8.5.3 the description of the specimen, the procedure, and practical examination checkpoints, as well as the results of the examination shall be documented.
8.22 Paragraph 8.5.4 Level I Practical Examination, proficiency shall be demonstrated in performing the applicable NDE technique on one or more specimens or machine problems approved by the NDE Level III and in evaluating the results to the degree of responsibility as described in the written practice. At least ten (10) different checkpoints requiring an understanding of examination variables and the procedural requirements shall be included in the practical examination. The candidate shall detect at least 80% of discontinuities and conditions specified by the NDE Level III.
8.23 Paragraph 8.5.5 Level II Practical Examination, proficiency shall be demonstrated in selecting and performing the applicable NDE technique, interpreting, and evaluating the results on specimens approved by the NDE Level III. At least ten (10) different checkpoints requiring an understanding of NDE variables and the procedural requirements shall be included in the practical examination.
8.24 Paragraph 8.5.6 shall not be allowed.
8.25 Paragraph 8.7 minimum numbers of examination questions shall be as necessary to meet referencing Code, Standards, and Specifications, in addition to those required by Mandatory Appendix II.
8.26 Paragraph 8.7.3.2 shall not be allowed.
8.27 Paragraph 8.7.4 and 8.7.5 shall not be allowed for Specific Examinations.

9.0 As described in SNT-TC-1A paragraph 9.0 Certification and subparagraphs 9.2, 9.4, and 9.4.7.
9.1 Paragraph 9.2 shall not be allowed.
9.2 Paragraph 9.4 personnel certification records shall be maintained on file by the employer for the duration specified in the written practice and shall include the information specified in subparagraphs of 9.3 except for 9.4.7 which shall not be allowed.

10.0 As described in SNT-TC-1A paragraph 10.0 Technical Performance Evaluation, subparagraph 10.2 shall be used except as modified above.

11.0 As described in SNT-TC-1A paragraph 11.0 Interrupted Service, subparagraph 11.1 and 11.2 the written practice shall include rules covering types and duration of interrupted service which specify reexamination and recertification requirements.

12.0 As described in SNT-TC-1A paragraph 12.0 Recertification, subparagraph 12.1, 12.2, and 12.3.
12.1 Paragraph 12.1 Recertification shall be by re-examination. Continuing satisfactory technical performance shall not be utilized for recertification without re-examination.
12.2 Paragraph 12.2 maximum recertification intervals shall be 3 years for Level I and Level II personnel, and 5 years for Level III personnel. Certifications expire 3 or 5 years from the date of the first examination taken during initial or recertification activities for each method.
12.3 Paragraph 12.3 when new techniques are added to the written practice, NDE personnel shall receive applicable training, take applicable examinations and obtain necessary experience, such that they meet requirements for new techniques, prior to their next recertification date.

13.0 As described in SNT-TC-1A paragraph 13.0 Termination, subparagraph 13.2.4.
13.1 Paragraph 13.2.4 Level I and Level II personnel shall be recertified by examination as specified above. Level III personnel may be recertified by written Method, Specific, and Practical Examinations and the Demonstration Examination. Alternatively, Level III personnel may be recertified using only the written Method and Specific Examinations, provided the following conditions are met:

13.1.1 Level III candidate was previously certified or recertified using all the written examinations and the Demonstration Examination.

13.1.2 Level III candidate is not being recertified due to interrupted service as defined in the written practice.

13.1.3 Level III candidate is not being certified by a new Employer.

13.1.4 For initial certification, the grades for the Basic, Method, Specific, Practical, and Demonstration Examinations shall be averaged to determine the overall grade. For recertification, the grades of applicable examinations shall be averaged to determine the overall grade.

MANDATORY APPENDIX IV EXCEPTIONS TO ASNT/ANSI CP-189 2016 EDITION

(19)

This Mandatory Appendix is used for the purpose of identifying exceptions to 2016 Edition of ASNT/ANSI CP-189 requirements for "Qualification and Certification of Nondestructive Testing Personnel." The requirements identified in this Mandatory Appendix take exception to those specific requirements as identified in the 2016 Edition of ASNT/ANSI CP-189 document.

In addition to Mandatory Appendix II, the following are exceptions and additions to CP-189 2016 Edition:

Section 2.0 Definitions - As described in CP-189 - paragraph 2.1.22
Add definition for Personalized Instruction;

2.1.22 **Personalized Instruction**. Personal Instruction may consist of blended classroom, supervised laboratory, and/or hybrid online competency-based course delivery. Modular content is addressed through online presentations, in the classroom, and/or in small groups. Personalized instruction also enables students to achieve competency using strategies that align with their knowledge, skills and learning styles.

Section 4.0 Qualification Requirements - As described in CP-189 paragraph 4.1.1.1
Delete self-study as an acceptable form of training.

4.1.1.1 The organized training may include instructor-led training, virtual instructor led training, computer-based training or web-based training. Computer-based training and web-based training shall track hours and content of training with student examinations in accordance with 4.1.2.

Section 6.0 Examinations - As described in CP-189 subparagraphs 6.1, 6.2, 6.4, 6.5 and 6.6;
Defined how long annually is

6.1.3 **Frequency**. Vision examinations shall be administered annually, except that color differentiation examinations need be repeated only at each recertification.

Removed the requirement for a Company Level III to be certified by ASNT for their Initial Certification

6.2.1 **Initial Requirement**. Prior to the employer's certification examinations, the candidate shall hold a current Level III for each method for which employer certification is sought, an ASNT Level III certificate with a currently valid endorsement can be accepted.

Removed waiver of employer based Specific Examination for ASNT certified Level II's

6.4 **ASNT NDT Level II Certificate**. The employer may accept a valid ASNT NDT Level II certificate as meeting the examination requirements of paragraphs 6.3.1 if the NDE Level III has determined that the ASNT examinations meet the requirements of the employer's certification procedure.

Removed waiver of employer based Specific Examination for ACCP certified Level II's

6.5 **ACCP Level II Certificate**. The employer may accept a valid ACCP Level II certificate as meeting the examination requirements of paragraphs 6.3.1 if the NDE Level III has determined that the ASNT examinations meet the requirements of the employer's certification procedure.

Mandated that the candidate receive at least an 80% on the Practical Examination

6.5.2 **Employer Examinations**. Examinations administered by the employer for qualification shall result in a passing composite grade of at least 80 percent, with no individual examination having a passing grade less than 70 percent. The Practical examination shall have a passing grade of at least 80 percent.

The Level III shall determine the minimum number of radiographs to be successfully reviewed by the Candidate seeking Limited Certification

6.6.4.1 **Film Interpretation Limited Certification**. The practical examination shall consist of the review and grading of a sufficient number of radiographs to demonstrate satisfactory performance to the certifying Level III or sufficient documented experience.

Added acronyms for PAUT and TOFD

6.6.4.2 **Phased Array Ultrasonic Testing (PAUT) and Time of Flight Diffraction (TOFD)**. Flawed samples used for practical examinations shall be representative of the components and/or configurations that the candidates would be testing under this endorsement and approved by the NDE Level III.

Section 7.0 Expiration, Suspension, Revocation, and Reinstatement of Employer Certification - As described in CP-189 subparagraphs 7.1.2 and Delete 7.1.3

Tied the expiration of a certification to when the examination was taken should it be taken over successive days

7.1.2 5 years from the day of the first examination for each method NDE Level I, NDE Level II and NDE Level III individuals;

Deleted 7.1.3 to eliminate the link between the employer certified Level III and ASNT Level III

Section 9.0 Records - As described in CP-189 subparagraphs 9.2.1.6

Added the requirement for the Level III to sign the candidate's certification

9.2.1.6 Signature of the NDE Level III that verified qualifications of candidate for certification shall be affixed to the certificate.

Appendix B Table - As described in CP-189

Remove footnote 1

NONMANDATORY APPENDIX A IMPERFECTION VS TYPE OF NDE METHOD

A-110 SCOPE

Table A-110 lists common imperfections and the NDE methods that are generally capable of detecting them.

CAUTION: Table A-110 should be regarded for general guidance only and not as a basis for requiring or prohibiting a particular type of NDE method for a specific application. For example, material and product form are factors that could result in differences from the degree of effectiveness implied in the table. For service-induced imperfections, accessibility and other conditions at the examination location are also significant factors that must be considered in selecting a particular NDE method. In addition, Table A-110 must not be considered to be all inclusive; there are several NDE methods/techniques and imperfections not listed in the table. The user must consider all applicable conditions when selecting NDE methods for a specific application.

Table A-110
Imperfection vs. Type of NDE Method

	Surface [Note (1)]		Subsurface [Note (2)]		Volumetric [Note (3)]				
	VT	PT	MT	ET	RT	UTA	UTS	AE	UTT
Service-Induced Imperfections									
Abrasive Wear (Localized)	◉	⊛	⊛	...	◉	⊛	⊛	...	⊛
Baffle Wear (Heat Exchangers)	◉	...	...	⊛	...	...	...	...	...
Corrosion-Assisted Fatigue Cracks	◎	⊛	◉	...	◎	◉	...	◉	...
Corrosion	...	...	...	...	...	...	...	...	...
-Crevice	◉	...	...	...	...	...	...	...	◎
-General / Uniform	...	...	...	◎	⊛	...	⊛	...	◉
-Pitting	◉	◉	◎	...	◉	◎	◎	⊛	◎
-Selective	◉	◉	◎	...	...	...	...	...	◎
Creep (Primary) [Note (4)]	...	...	...	...	...	...	...	...	...
Erosion	◉	...	...	...	◉	◎	⊛	...	⊛
Fatigue Cracks	◎	◉	◉	⊛	⊛	◉	...	◉	...
Fretting (Heat Exchanger Tubing)	⊛	...	...	⊛	...	...	...	...	⊛
Hot Cracking	...	⊛	⊛	...	⊛	◎	...	⊛	...
Hydrogen-Induced Cracking	...	⊛	⊛	...	◎	⊛	...	⊛	...
Intergranular Stress-Corrosion Cracks	...	...	...	...	...	◎	...	...	...
Stress-Corrosion Cracks (Transgranular)	◎	⊛	◉	◎	⊛	⊛	...	⊛	...
Welding Imperfections									
Burn Through	◉	...	...	...	◉	⊛	...	...	◎
Cracks	◎	◉	◉	⊛	⊛	◉	◎	◉	...
Excessive/Inadequate Reinforcement	◉	...	...	...	◉	⊛	◎	...	◎
Inclusions (Slag/Tungsten)	...	...	⊛	⊛	◉	⊛	◎	◎	...
Incomplete Fusion	⊛	...	⊛	⊛	⊛	◉	⊛	⊛	...
Incomplete Penetration	⊛	◉	◉	⊛	◉	◉	⊛	⊛	...
Misalignment	◉	...	...	...	◉	⊛	...	...	...
Overlap	⊛	◉	◉	◎	...	◎	...	...	...
Porosity	◉	◉	◎	...	◉	⊛	◎	◎	...
Root Concavity	◉	...	...	...	◉	⊛	◎	◎	◎
Undercut	◉	⊛	⊛	◎	◉	⊛	◎	◎	...
Product Form Imperfections									
Bursts (Forgings)	◎	◉	◉	⊛	⊛	⊛	⊛	◉	...
Cold Shuts (Castings)	◎	◉	◉	◎	◉	⊛	⊛	◎	...
Cracks (All Product Forms)	◎	◉	◉	⊛	⊛	⊛	◎	◉	...
Hot Tear (Castings)	◎	◉	◉	⊛	⊛	⊛	◎	◎	...

Table A-110
Imperfection vs. Type of NDE Method (Cont'd)

	Surface [Note (1)]		Subsurface [Note (2)]		Volumetric [Note (3)]				
	VT	PT	MT	ET	RT	UTA	UTS	AE	UTT
Inclusions (All Product Forms)	...	...	⊛	⊛	◉	⊛	◎	◎	...
Lamination (Plate, Pipe)	◎	⊛	⊛	...	...	◎	◉	◎	◉
Laps (Forgings)	◎	◉	◉	◎	⊛	...	◎	◎	...
Porosity (Castings)	◉	◉	◎	...	◉	◎	◎	◎	...
Seams (Bar, Pipe)	◎	◉	◉	⊛	◎	⊛	⊛	◎	...

Legend:
- AE — Acoustic Emission
- ET — Electromagnetic (Eddy Current)
- MT — Magnetic Particle
- PT — Liquid Penetrant
- RT — Radiography
- UTA — Ultrasonic Angle Beam
- UTS — Ultrasonic Straight Beam
- UTT — Ultrasonic Thickness Measurements
- VT — Visual

◉ — All or most standard techniques will detect this imperfection under all or most conditions.

⊛ — One or more standard technique(s) will detect this imperfection under certain conditions.

◎ — Special techniques, conditions, and/or personnel qualifications are required to detect this imperfection.

GENERAL NOTE: Table A-110 lists imperfections and NDE methods that are capable of detecting them. It must be kept in mind that this table is very general in nature. Many factors influence the detectability of imperfections. This table assumes that only qualified personnel are performing nondestructive examinations and good conditions exist to permit examination (good access, surface conditions, cleanliness, etc.).

NOTES:
(1) Methods capable of detecting imperfections that are open to the surface only.
(2) Methods capable of detecting imperfections that are either open to the surface or slightly subsurface.
(3) Methods capable of detecting imperfections that may be located anywhere within the examined volume.
(4) Various NDE methods are capable of detecting tertiary (3rd stage) creep and some, particularly using special techniques, are capable of detecting secondary (2nd stage) creep. There are various descriptions/definitions for the stages of creep and a particular description/definition will not be applicable to all materials and product forms.

ARTICLE 2
RADIOGRAPHIC EXAMINATION

T-210 SCOPE

The radiographic method described in this Article for examination of materials including castings and welds shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Article 1, Mandatory Appendix I, I-121.1, RT — Radiography.

Certain product-specific, technique-specific, and application-specific requirements are also given in other Mandatory Appendices of this Article, as listed in the table of contents. These additional requirements shall also be complied with when an Appendix is applicable to the radiographic or radioscopic examination being conducted.

T-220 GENERAL REQUIREMENTS

T-221 PROCEDURE REQUIREMENTS

T-221.1 Written Procedure. Radiographic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material type and thickness range

(b) isotope or maximum X-ray voltage used

(c) source-to-object distance (D in T-274.1)

(d) distance from source side of object to film (d in T-274.1)

(e) source size (F in T-274.1)

(f) film brand and designation

(g) screens used

T-221.2 Procedure Demonstration. Demonstration of the density and image quality indicator (IQI) image requirements of the written procedure on production or technique radiographs shall be considered satisfactory evidence of compliance with that procedure.

T-222 SURFACE PREPARATION

T-222.1 Materials Including Castings. Surfaces shall satisfy the requirements of the applicable materials specification or referencing Code Section, with additional conditioning, if necessary, by any suitable process to such a degree that the images of surface irregularities cannot mask or be confused with the image of any discontinuity on the resulting radiograph.

T-222.2 Welds. The weld ripples or weld surface irregularities on both the inside (where accessible) and outside shall be removed by any suitable process to such a degree that the images of surface irregularities cannot mask or be confused with the image of any discontinuity on the resulting radiograph.

The finished surface of all butt-welded joints may be flush with the base material or may have reasonably uniform crowns, with reinforcement not to exceed that specified in the referencing Code Section.

T-223 BACKSCATTER RADIATION (19)

A lead symbol "B," with minimum dimensions of $^7/_{16}$ in. (11 mm) in height and $^1/_{16}$ in. (1.5 mm) in thickness, shall be attached to the back of each film holder during each exposure to determine if backscatter radiation is exposing the film. The lead symbol "B" shall be placed in a location so that it would appear within an area on the radiograph that meets the requirements of T-282, VIII-288, or IX-288, as applicable.

T-224 SYSTEM OF IDENTIFICATION (19)

A system shall be used to produce permanent identification on each radiograph traceable to the contract, component, weld or weld seam, or part numbers, as appropriate. In addition, the Manufacturer's symbol or name and the date of the radiograph shall be plainly and permanently included on the radiograph. An NDE subcontractor's name or symbol may also be used together with that of the Manufacturer. This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

T-225 MONITORING DENSITY LIMITATIONS OF RADIOGRAPHS

Either a densitometer or step wedge comparison film shall be used for judging film density.

T-226 EXTENT OF EXAMINATION

The extent of radiographic examination shall be as specified by the referencing Code Section.

T-230 EQUIPMENT AND MATERIALS

T-231 FILM

T-231.1 Selection. Radiographs shall be made using industrial radiographic film.

T-231.2 Processing. Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing, SE-999, or Sections 23 through 26 of Standard Guide for Radiographic Examination, SE-94, may be used as a guide for processing film, except that Section 8.1 of SE-999 is not required.

T-232 INTENSIFYING SCREENS

Intensifying screens may be used when performing radiographic examination in accordance with this Article.

T-233 IMAGE QUALITY INDICATOR (IQI) DESIGN

T-233.1 Standard IQI Design. IQIs shall be either the hole type or the wire type. Hole-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-1025. Wire-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-747, except that the largest wire number or the identity number may be omitted. ASME standard IQIs shall consist of those in Table T-233.1 for hole type and those in Table T-233.2 for wire type.

Table T-233.2
Wire IQI Designation, Wire Diameter, and Wire Identity

Set A		Set B	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.0032 (0.08)	1	0.010 (0.25)	6
0.004 (0.10)	2	0.013 (0.33)	7
0.005 (0.13)	3	0.016 (0.41)	8
0.0063 (0.16)	4	0.020 (0.51)	9
0.008 (0.20)	5	0.025 (0.64)	10
0.010 (0.25)	6	0.032 (0.81)	11

Set C		Set D	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.032 (0.81)	11	0.100 (2.54)	16
0.040 (1.02)	12	0.126 (3.20)	17
0.050 (1.27)	13	0.160 (4.06)	18
0.063 (1.60)	14	0.200 (5.08)	19
0.080 (2.03)	15	0.250 (6.35)	20
0.100 (2.54)	16	0.320 (8.13)	21

Table T-233.1
Hole-Type IQI Designation, Thickness, and Hole Diameters

IQI Designation	IQI Thickness, in. (mm)	1*T* Hole Diameter, in. (mm)	2*T* Hole Diameter, in. (mm)	4*T* Hole Diameter, in. (mm)
5	0.005 (0.13)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
7	0.0075 (0.19)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
10	0.010 (0.25)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
12	0.0125 (0.32)	0.0125 (0.32)	0.025 (0.64)	0.050 (1.27)
15	0.015 (0.38)	0.015 (0.38)	0.030 (0.76)	0.060 (1.52)
17	0.0175 (0.44)	0.0175 (0.44)	0.035 (0.89)	0.070 (1.78)
20	0.020 (0.51)	0.020 (0.51)	0.040 (1.02)	0.080 (2.03)
25	0.025 (0.64)	0.025 (0.64)	0.050 (1.27)	0.100 (2.54)
30	0.030 (0.76)	0.030 (0.76)	0.060 (1.52)	0.120 (3.05)
35	0.035 (0.89)	0.035 (0.89)	0.070 (1.78)	0.140 (3.56)
40	0.040 (1.02)	0.040 (1.02)	0.080 (2.03)	0.160 (4.06)
45	0.045 (1.14)	0.045 (1.14)	0.090 (2.29)	0.180 (4.57)
50	0.050 (1.27)	0.050 (1.27)	0.100 (2.54)	0.200 (5.08)
60	0.060 (1.52)	0.060 (1.52)	0.120 (3.05)	0.240 (6.10)
70	0.070 (1.78)	0.070 (1.78)	0.140 (3.56)	0.280 (7.11)
80	0.080 (2.03)	0.080 (2.03)	0.160 (4.06)	0.320 (8.13)
100	0.100 (2.54)	0.100 (2.54)	0.200 (5.08)	0.400 (10.16)
120	0.120 (3.05)	0.120 (3.05)	0.240 (6.10)	0.480 (12.19)
140	0.140 (3.56)	0.140 (3.56)	0.280 (7.11)	0.560 (14.22)
160	0.160 (4.06)	0.160 (4.06)	0.320 (8.13)	0.640 (16.26)
200	0.200 (5.08)	0.200 (5.08)	0.400 (10.16)	...
240	0.240 (6.10)	0.240 (6.10)	0.480 (12.19)	...
280	0.280 (7.11)	0.280 (7.11)	0.560 (14.22)	...

T-233.2 Alternative IQI Design. IQIs designed and manufactured in accordance with other national or international standards may be used provided the requirements of either (a) or (b) below, and the material requirements of T-276.1 are met.

(a) Hole-Type IQIs. The calculated Equivalent IQI Sensitivity (EPS), per SE-1025, Appendix X1, is equal to or better than the required standard hole-type IQI.

(b) Wire-Type IQIs. The alternative wire IQI essential wire diameter is equal to or less than the required standard IQI essential wire.

T-234 FACILITIES FOR VIEWING OF RADIOGRAPHS

Viewing facilities shall provide subdued background lighting of an intensity that will not cause reflections, shadows, or glare on the radiograph that interfere with the interpretation process. Equipment used to view radiographs for interpretation shall provide a variable light source sufficient for the essential IQI hole or designated wire to be visible for the specified density range. The viewing conditions shall be such that light from around the outer edge of the radiograph or coming through low-density portions of the radiograph does not interfere with interpretation.

T-260 CALIBRATION

T-261 SOURCE SIZE

T-261.1 Verification of Source Size. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification.

T-261.2 Determination of Source Size. When manufacturer's or supplier's publications are not available, source size may be determined as follows:

(a) X-Ray Machines. For X-ray machines operating at 1,000 kV and less, the focal spot size may be determined in accordance with SE-1165, Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging.

(b) Iridium-192 Sources. For Iridium-192, the source size may be determined in accordance with SE-1114, Standard Test Method for Determining the Focal Size of Iridium-192 Industrial Radiographic Sources.

T-262 DENSITOMETER AND STEP WEDGE COMPARISON FILM

(19) **T-262.1 Densitometers.** Densitometers shall be calibrated at least every 3 months during use as follows:

(a) A national standard step tablet or a step wedge calibration film, traceable to a national standard step tablet and having at least five steps with neutral densities from at least 1.0 through 4.0, shall be used. The step wedge calibration film shall have been verified within the last year by comparison with a national standard step tablet unless, prior to first use, it was maintained in the original light-tight and waterproof sealed package as supplied by the manufacturer. Step wedge calibration films may be used without verification for one year upon opening, provided it is within the manufacturer's stated shelf life.

(b) The densitometer manufacturer's step-by-step instructions for the operation of the densitometer shall be followed.

(c) The density steps closest to 1.0, 2.0, 3.0, and 4.0 on the national standard step tablet or step wedge calibration film shall be read.

(d) The densitometer is acceptable if the density readings do not vary by more than ±0.05 density units from the actual density stated on the national standard step tablet or step wedge calibration film.

T-262.2 Step Wedge Comparison Films. Step wedge comparison films shall be verified prior to first use, unless performed by the manufacturer, as follows:

(a) The density of the steps on a step wedge comparison film shall be verified by a calibrated densitometer.

(b) The step wedge comparison film is acceptable if the density readings do not vary by more than ±0.1 density units from the density stated on the step wedge comparison film.

T-262.3 Periodic Verification.

(a) Densitometers. Periodic cablibration verification checks shall be performed as described in T-262.1 at the beginning of each shift, after 8 hr of continuous use, or after change of apertures, whichever comes first.

(b) Step Wedge Comparison Films. Verification checks shall be performed annually per T-262.2.

T-262.4 Documentation.

(a) Densitometers. Densitometer calibrations required by T-262.1 shall be documented, but the actual readings for each step do not have to be recorded. Periodic densitometer verification checks required by T-262.3(a) do not have to be documented.

(b) Step Wedge Calibration Films. Step wedge calibration film verifications required by T-262.1(a) shall be documented, but the actual readings for each step do not have to be recorded.

(c) Step Wedge Comparison Films. Step wedge comparison film verifications required by T-262.2 and T-262.3(b) shall be documented, but the actual readings for each step do not have to be recorded.

T-270 EXAMINATION

T-271 RADIOGRAPHIC TECHNIQUE[5]

A single-wall exposure technique shall be used for radiography whenever practical. When it is not practical to use a single-wall technique, a double-wall technique shall be used. An adequate number of exposures shall be made to demonstrate that the required coverage has been obtained.

T-271.1 Single-Wall Technique. In the single-wall technique, the radiation passes through only one wall of the weld (material), which is viewed for acceptance on the radiograph.

T-271.2 Double-Wall Technique. When it is not practical to use a single-wall technique, one of the following double-wall techniques shall be used.

(a) Single-Wall Viewing. For materials and for welds in components, a technique may be used in which the radiation passes through two walls and only the weld (material) on the film-side wall is viewed for acceptance on the radiograph. When complete coverage is required for circumferential welds (materials), a minimum of three exposures taken 120 deg to each other shall be made.

(b) Double-Wall Viewing. For materials and for welds in components $3^1/_2$ in. (89 mm) or less in nominal outside diameter, a technique may be used in which the radiation passes through two walls and the weld (material) in both walls is viewed for acceptance on the same radiograph. For double-wall viewing, only a source-side IQI shall be used.

(1) For welds, the radiation beam may be offset from the plane of the weld at an angle sufficient to separate the images of the source-side and film-side portions of the weld so that there is no overlap of the areas to be interpreted. When complete coverage is required, a minimum of two exposures taken 90 deg to each other shall be made for each joint.

(2) As an alternative, the weld may be radiographed with the radiation beam positioned so that the images of both walls are superimposed. When complete coverage is required, a minimum of three exposures taken at either 60 deg or 120 deg to each other shall be made for each joint.

(3) Additional exposures shall be made if the required radiographic coverage cannot be obtained using the minimum number of exposures indicated in (1) or (2) above.

T-272 RADIATION ENERGY

The radiation energy employed for any radiographic technique shall achieve the density and IQI image requirements of this Article.

T-273 DIRECTION OF RADIATION

The direction of the central beam of radiation should be centered on the area of interest whenever practical.

T-274 GEOMETRIC UNSHARPNESS

T-274.1 Geometric Unsharpness Determination. Geometric unsharpness of the radiograph shall be determined in accordance with:

$$U_g = Fd / D$$

where

D = distance from source of radiation to weld or object being radiographed
d = distance from source side of weld or object being radiographed to the film
F = source size: the maximum projected dimension of the radiating source (or effective focal spot) in the plane perpendicular to the distance D from the weld or object being radiographed
U_g = geometric unsharpness

D and d shall be determined at the approximate center of the area of interest.

NOTE: Alternatively, a nomograph as shown in Standard Guide for Radiographic Examination SE-94 may be used.

T-274.2 Geometric Unsharpness Limitations. Recommended maximum values for geometric unsharpness are as follows:

Material Thickness, in. (mm)	U_g Maximum, in. (mm)
Under 2 (50)	0.020 (0.51)
2 through 3 (50–75)	0.030 (0.76)
Over 3 through 4 (75–100)	0.040 (1.02)
Greater than 4 (100)	0.070 (1.78)

NOTE: Material thickness is the thickness on which the IQI is based.

T-275 LOCATION MARKERS

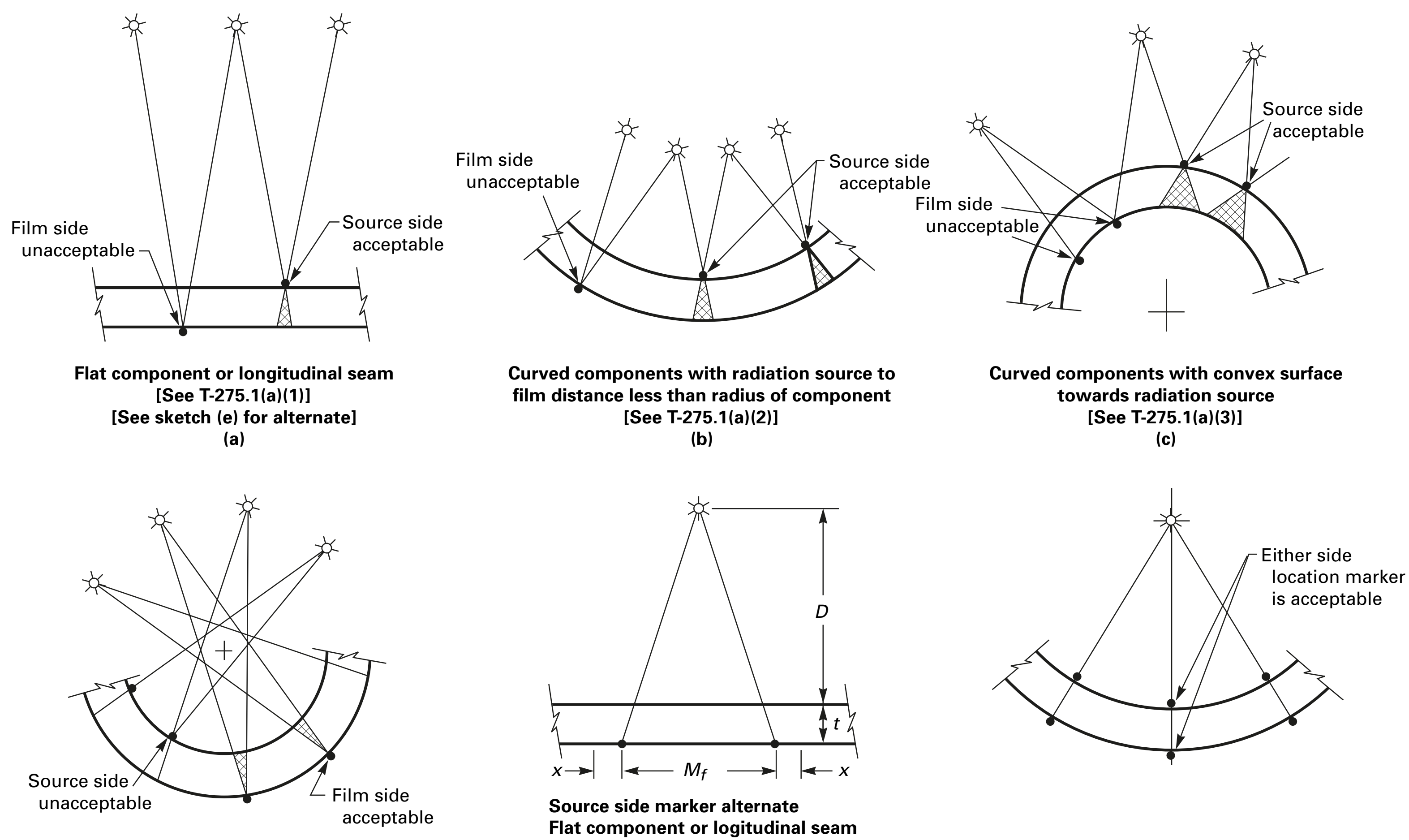
Location markers (see Figure T-275), which shall appear as radiographic images on the radiograph, shall be placed on the part, not on the exposure holder/cassette. Their locations shall be permanently marked on the surface of the part being radiographed when permitted, or on a map, in a manner permitting the area of interest on a radiograph to be accurately traceable to its location on the part, for the required retention period of the radiograph. Evidence shall also be provided on the radiograph that the required coverage of the region being examined has been obtained. Location markers shall be placed as follows.

T-275.1 Single-Wall Viewing.

(a) Source-Side Markers. Location markers shall be placed on the source side when radiographing the following:

(1) flat components or longitudinal joints in cylindrical or conical components;

Figure T-275
Location Marker Sketches



Flat component or longitudinal seam
[See T-275.1(a)(1)]
[See sketch (e) for alternate]
(a)

Curved components with radiation source to film distance less than radius of component
[See T-275.1(a)(2)]
(b)

Curved components with convex surface towards radiation source
[See T-275.1(a)(3)]
(c)

Curved components with radiation source to film distance greater than radius of curvature
[See T-275.1(b)(1)]
(d)

Source side marker alternate
Flat component or logitudinal seam

$x = (t / D)(M_f / 2)$

x = **additional required coverage beyond film side location marker**
t = **component thickness**
M_f = **film side location marker interval**
D = **source to component distance**

[See T-275.1(b)(2)]
(e)

Curved components with radiation source at center curvature
[See T-275.1(c)]
(f)

LEGEND: Radiation source — ☼
Location marker — •
Component center — +

(2) curved or spherical components whose concave side is toward the source and when the "source-to-material" distance is less than the inside radius of the component;

(3) curved or spherical components whose convex side is toward the source.

(b) Film-Side Markers

(1) Location markers shall be placed on the film side when radiographing either curved or spherical components whose concave side is toward the source and when the "source-to-material" distance is greater than the inside radius.

(2) As an alternative to source-side placement in T-275.1(a)(1), location markers may be placed on the film side when the radiograph shows coverage beyond the location markers to the extent demonstrated by Figure T-275, sketch (e), and when this alternate is documented in accordance with T-291.

(c) Either Side Markers. Location markers may be placed on either the source side or film side when radiographing either curved or spherical components whose concave side is toward the source and the "source-to-material" distance equals the inside radius of the component.

T-275.2 Double-Wall Viewing. For double-wall viewing, at least one location marker shall be placed adjacent to the weld (or on the material in the area of interest) for each radiograph.

T-275.3 Mapping the Placement of Location Markers. When inaccessibility or other limitations prevent the placement of markers as stipulated in T-275.1 and T-275.2, a dimensioned map of the actual marker placement shall accompany the radiographs to show that full coverage has been obtained.

T-276 IQI SELECTION

T-276.1 Material. IQIs shall be selected from either the same alloy material group or grade as identified in SE-1025 for hole type or SE-747 for wire type, or from an alloy material group or grade with less radiation absorption than the material being radiographed.

(19) **T-276.2 Size.** The designated hole IQI or essential wire shall be as specified in Table T-276. A thinner or thicker hole-type IQI may be substituted for any section thickness listed in Table T-276, provided an equivalent IQI sensitivity is maintained. See T-283.2.

(a) Welds With Reinforcements. The thickness on which the IQI is based is the nominal single-wall material thickness plus the weld reinforcement thickness estimated to be present on both sides of the weld (I.D. and O.D.). The values used for the estimated weld reinforcement thicknesses shall be representative of the weld conditions and shall not exceed the maximums permitted by the referencing Code Section. Physical measurement of the actual weld reinforcements is not required. Backing rings or strips shall not be considered as part of the thickness in IQI selection.

(b) Welds Without Reinforcements. The thickness on which the IQI is based is the nominal single-wall material thickness. Backing rings or strips shall not be considered as part of the thickness in IQI selection.

(c) Actual Values. With regard to (a) and (b) above, when the actual material/weld thickness is measured, IQI selection may be based on these known values.

T-276.3 Welds Joining Dissimilar Materials or Welds With Dissimilar Filler Metal. When the weld metal is of an alloy group or grade that has a radiation attenuation that differs from the base material, the IQI material selection shall be based on the weld metal and be in accordance with T-276.1. When the density limits of T-282.2 cannot be met with one IQI, and the exceptional density area(s) is at the interface of the weld metal and the base metal, the material selection for the additional IQIs shall be based on the base material and be in accordance with T-276.1.

T-277 USE OF IQIS TO MONITOR RADIOGRAPHIC EXAMINATION

T-277.1 Placement of IQIs. (19)

(a) Source-Side IQI(s). The IQI(s) shall be placed on the source side of the part being examined, except for the condition described in (b).

When, due to part or weld configuration or size, it is not practical to place the IQI(s) on the part or weld, the IQI(s) may be placed on a separate block. Separate blocks shall be made of the same or radiographically similar materials (as defined in SE-1025) and may be used to facilitate IQI positioning. There is no restriction on the separate block thickness, provided the IQI/area-of-interest density tolerance requirements of T-282.2 are met.

(1) The IQI on the source side of the separate block shall be placed no closer to the film than the source side of the part being radiographed.

(2) The separate block shall be placed as close as possible to the part being radiographed.

(3) When hole-type IQIs are used, the block dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible on the radiograph.

(b) Film-Side IQI(s). Where inaccessibility prevents hand placing the IQI(s) on the source side, the IQI(s) shall be placed on the film side in contact with the part being examined. A lead letter "F" shall be placed adjacent to or on the IQI(s), but shall not mask the essential hole where hole IQIs are used.

(c) IQI Placement for Welds — Hole IQIs. The IQI(s) may be placed adjacent to or on the weld. The identification number(s) and, when used, the lead letter "F," shall not be in the area of interest, except when geometric configuration makes it impractical.

Table T-276
IQI Selection

Nominal Single-Wall Material Thickness Range, in. (mm)	IQI					
	Source Side			Film Side		
	Hole-Type Designation	Essential Hole	Wire-Type Essential Wire	Hole-Type Designation	Essential Hole	Wire-Type Essential Wire
Up to 0.25, incl. (6.4)	12	2*T*	5	10	2*T*	4
Over 0.25 through 0.375 (6.4 through 9.5)	15	2*T*	6	12	2*T*	5
Over 0.375 through 0.50 (9.5 through 12.7)	17	2*T*	7	15	2*T*	6
Over 0.50 through 0.75 (12.7 through 19.0)	20	2*T*	8	17	2*T*	7
Over 0.75 through 1.00 (19.0 through 25.4)	25	2*T*	9	20	2*T*	8
Over 1.00 through 1.50 (25.4 through 38.1)	30	2*T*	10	25	2*T*	9
Over 1.50 through 2.00 (38.1 through 50.8)	35	2*T*	11	30	2*T*	10
Over 2.00 through 2.50 (50.8 through 63.5)	40	2*T*	12	35	2*T*	11
Over 2.50 through 4.00 (63.5 through 101.6)	50	2*T*	13	40	2*T*	12
Over 4.00 through 6.00 (101.6 through 152.4)	60	2*T*	14	50	2*T*	13
Over 6.00 through 8.00 (152.4 through 203.2)	80	2*T*	16	60	2*T*	14
Over 8.00 through 10.00 (203.2 through 254.0)	100	2*T*	17	80	2*T*	16
Over 10.00 through 12.00 (254.0 through 304.8)	120	2*T*	18	100	2*T*	17
Over 12.00 through 16.00 (304.8 through 406.4)	160	2*T*	20	120	2*T*	18
Over 16.00 through 20.00 (406.4 through 508.0)	200	2*T*	21	160	2*T*	20

(d) IQI Placement for Welds — Wire IQIs. The IQI(s) shall be placed on the weld so that the lengths of the wires are transverse to the longitudinal axis of the weld. The IQI identification and, when used, the lead letter "F," shall not be in the area of interest, except when geometric configuration makes it impractical.

(e) IQI Placement for Materials Other Than Welds. The IQI(s) with the IQI identification and, when used, the lead letter "F," may be placed in the area of interest.

T-277.2 Number of IQIs. When one or more film holders are used for an exposure, at least one IQI image shall appear on each radiograph except as outlined in (b) below.

(a) Multiple IQIs. If the requirements of T-282 are met by using more than one IQI, one shall be representative of the lightest area of interest and the other the darkest area of interest; the intervening densities on the radiograph shall be considered as having acceptable density.

(b) Special Cases[6]

(1) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, spaced approximately 120 deg apart, are required under the following conditions:

(-a) When the complete circumference is radiographed using one or more film holders, or;

(-b) When a section or sections of the circumference, where the length between the ends of the outermost sections span 240 or more deg, is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

(2) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, with one placed at each end of the span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(-a) When a section of the circumference, the length of which is greater than 120 deg and less than 240 deg, is radiographed using just one film holder, or;

(-b) When a section or sections of the circumference, where the length between the ends of the outermost sections span less than 240 deg, is radiographed using more than one film holder.

(3) In (1) and (2) above, where sections of longitudinal welds adjoining the circumferential weld are radiographed simultaneously with the circumferential weld, an additional IQI shall be placed on each longitudinal weld at the end of the section most remote from the junction with the circumferential weld being radiographed.

(4) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, spaced approximately 120 deg apart, are required under the following conditions:

(-a) When a complete circumference is radiographed using one or more film holders, or;

(-b) When a section or sections of a circumference, where the length between the ends of the outermost sections span 240 or more deg, is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

(5) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, with one placed at each end of the span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(-a) When a section of a circumference, the length of which is greater than 120 deg and less than 240 deg, is radiographed using just one film holder, or;

(-b) When a section or sections of a circumference, where the length between the ends of the outermost sections span less than 240 deg is radiographed using more than one film holder.

(6) In (4) and (5) above, where other welds are radiographed simultaneously with the circumferential weld, one additional IQI shall be placed on each other weld.

(7) For segments of a flat or curved (i.e., ellipsoidal, torispherical, toriconical, elliptical, etc.) component where the source is placed perpendicular to the center of a length of weld for a single exposure when using more than three film holders, at least three IQIs, one placed at each end of the radiographed span and one in the approximate center of the span, are required.

(8) When an array of components in a circle is radiographed, at least one IQI shall show on each component image.

(9) In order to maintain the continuity of records involving subsequent exposures, all radiographs exhibiting IQIs that qualify the techniques permitted in accordance with (1) through (7) above shall be retained.

T-277.3 Shims Under Hole-Type IQIs. For welds, a shim of material radiographically similar to the weld metal shall be placed between the part and the IQI, if needed, so that the radiographic density throughout the area of interest is no more than minus 15% from (lighter than) the radiographic density through the designated IQI adjacent to the essential hole.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible in the radiograph.

T-280 EVALUATION

T-281 QUALITY OF RADIOGRAPHS

All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they do not mask and are not confused with the image of any discontinuity in the area of interest of the object being radiographed. Such blemishes include, but are not limited to:

(a) fogging;

(b) processing defects such as streaks, watermarks, or chemical stains;

(c) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears;

(d) false indications due to defective screens.

T-282 RADIOGRAPHIC DENSITY

T-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the designated hole-type IQI adjacent to the essential hole or adjacent to the essential wire of a wire-type IQI and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma ray source. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

T-282.2 Density Variation.

(a) The density of the radiograph anywhere through the area of interest shall not

(1) vary by more than minus 15% or plus 30% from the density through the body of the designated hole-type IQI adjacent to the essential hole or adjacent to the essential wire of a wire-type IQI, and

(2) exceed the minimum/maximum allowable density ranges specified in T-282.1

When calculating the allowable variation in density, the calculation may be rounded to the nearest 0.1 within the range specified in T-282.1.

(b) When the requirements of (a) above are not met, then an additional IQI shall be used for each exceptional area or areas and the radiograph retaken.

(c) When shims are used with hole-type IQIs, the plus 30% density restriction of (a) above may be exceeded, and the minimum density requirements of T-282.1 do not apply for the IQI, provided the required IQI sensitivity of T-283.1 is met.

T-283 IQI SENSITIVITY

T-283.1 Required Sensitivity. Radiography shall be performed with a technique of sufficient sensitivity to display the designated hole-type IQI image and the essential hole, or the essential wire of a wire-type IQI. The radiographs shall also display the IQI identifying numbers and letters. If the designated hole-type IQI image and essential hole, or essential wire of a wire-type IQI, do not show on any film in a multiple film technique, but do show in composite film viewing, interpretation shall be permitted only by composite film viewing. (**19**)

For wire-type IQIs, the essential wire shall be visible within the area of interest representing the thickness used for determining the essential wire, inclusive of the allowable density variations described in T-282.2.

T-283.2 Equivalent Hole-Type IQI Sensitivity. A thinner or thicker hole-type IQI than the designated IQI may be substituted, provided an equivalent or better IQI sensitivity, as listed in Table T-283, is achieved and all other requirements for radiography are met. Equivalent IQI sensitivity is shown in any row of Table T-283 which contains the designated IQI and hole. Better IQI sensitivity is shown in any row of Table T-283 which is above the equivalent sensitivity row. If the designated IQI and hole are not represented in the table, the next thinner IQI row from Table T-283 may be used to establish equivalent IQI sensitivity.

T-284 EXCESSIVE BACKSCATTER

If a light image of the "B," as described in T-223, appears on a darker background of the radiograph, protection from backscatter is insufficient and the radiograph shall be considered unacceptable. A dark image of the "B" on a lighter background is not cause for rejection.

T-285 EVALUATION BY MANUFACTURER

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed radiographs to assure compliance with the requirements of Article 2 and the referencing Code Section. As an aid to the review and evaluation, the radiographic technique documentation required by T-291 shall be completed prior to the evaluation. The radiograph review form required by T-292 shall be completed during the evaluation. The radiographic technique details and the radiograph review form documentation shall accompany the radiographs. Acceptance shall be completed prior to presentation of the radiographs and accompanying documentation to the Inspector.

Table T-283
Equivalent Hole-Type IQI Sensitivity

Hole-Type Designation	Equivalent Hole-Type Designations	
2*T* Hole	1*T* Hole	4*T* Hole
10	15	5
12	17	7
15	20	10
17	25	12
20	30	15
25	35	17
30	40	20
35	50	25
40	60	30
50	70	35
60	80	40
80	120	60
100	140	70
120	160	80
160	240	120
200	280	140

T-290 DOCUMENTATION

T-291 RADIOGRAPHIC TECHNIQUE DOCUMENTATION DETAILS

The organization shall prepare and document the radiographic technique details. As a minimum, the following information shall be provided.

(a) the requirements of Article 1, T-190(a)

(b) identification as required by T-224

(c) the dimensional map (if used) of marker placement in accordance with T-275.3

(d) number of radiographs (exposures)

(e) X-ray voltage or isotope type used

(f) source size (*F* in T-274.1)

(g) base material type and thickness, weld thickness, weld reinforcement thickness, as applicable

(h) source-to-object distance (*D* in T-274.1)

(i) distance from source side of object to film (*d* in T-274.1)

(j) film manufacturer and their assigned type/designation

(k) number of film in each film holder/cassette

(l) single- or double-wall exposure

(m) single- or double-wall viewing

T-292 RADIOGRAPH REVIEW FORM

The Manufacturer shall be responsible for the preparation of a radiograph review form. As a minimum, the following information shall be provided.

(a) a listing of each radiograph location

(b) the information required in T-291, by inclusion of the information on the review form or by reference to an attached radiographic technique details sheet

(c) evaluation and disposition of the material(s) or weld(s) examined

(d) identification (name) of the Manufacturer's representative who performed the final acceptance of the radiographs

(e) date of Manufacturer's evaluation

MANDATORY APPENDIX I
IN-MOTION RADIOGRAPHY

I-210 SCOPE

In-motion radiography is a technique of film radiography where the object being radiographed and/or the source of radiation is in motion during the exposure.

In-motion radiography may be performed on weldments when the following modified provisions to those in Article 2 are satisfied.

This Appendix is not applicable to computed radiographic (CR) or digital radiographic (DR) techniques.

I-220 GENERAL REQUIREMENTS

I-223 BACKSCATTER DETECTION SYMBOL LOCATION

(a) For longitudinal welds the lead symbol "B" shall be attached to the back of each film cassette or at approximately equal intervals not exceeding 36 in. (914 mm) apart, whichever is smaller.

(b) For circumferential welds, the lead symbol "B" shall be attached to the back of the film cassette in each quadrant or spaced no greater than 36 in. (914 mm), whichever is smaller.

(c) The lead symbol "B" shall be placed in a location so that it would appear within an area on the radiograph that meets the requirements of T-282.

I-260 CALIBRATION

I-263 BEAM WIDTH

The beam width shall be controlled by a metal diaphragm such as lead. The diaphragm for the energy selected shall be at least 10 half value layers thick.

The beam width as shown in Figure I-263 shall be determined in accordance with:

$$w = \frac{c(F + a)}{b} + a$$

where

a = slit width in diaphragm in direction of motion
b = distance from source to the weld side of the diaphragm
c = distance from weld side of the diaphragm to the source side of the weld surface
F = source size: the maximum projected dimension of the radiating source (or focal spot) in the plane perpendicular to the distance $b + c$ from the weld being radiographed
w = beam width at the source side of the weld measured in the direction of motion

NOTE: Use consistent units.

I-270 EXAMINATION

I-274 GEOMETRIC AND IN-MOTION UNSHARPNESS

I-274.1 Geometric Unsharpness. Geometric unsharpness for in-motion radiography shall be determined in accordance with T-274.1.

I-274.2 In-Motion Unsharpness. In-motion unsharpness of the radiograph shall be determined in accordance with:

$$U_M = \frac{wd}{D}$$

where

D = distance from source of radiation to weld being radiographed
d = distance from source side of the weld being radiographed to the film
U_M = in-motion unsharpness
w = beam width at the source side of the weld measured in the direction of motion determined as specified in I-263

NOTE: Use consistent units.

I-274.3 Unsharpness Limitations. Recommended maximum values for geometric unsharpness and in-motion unsharpness are provided in T-274.2.

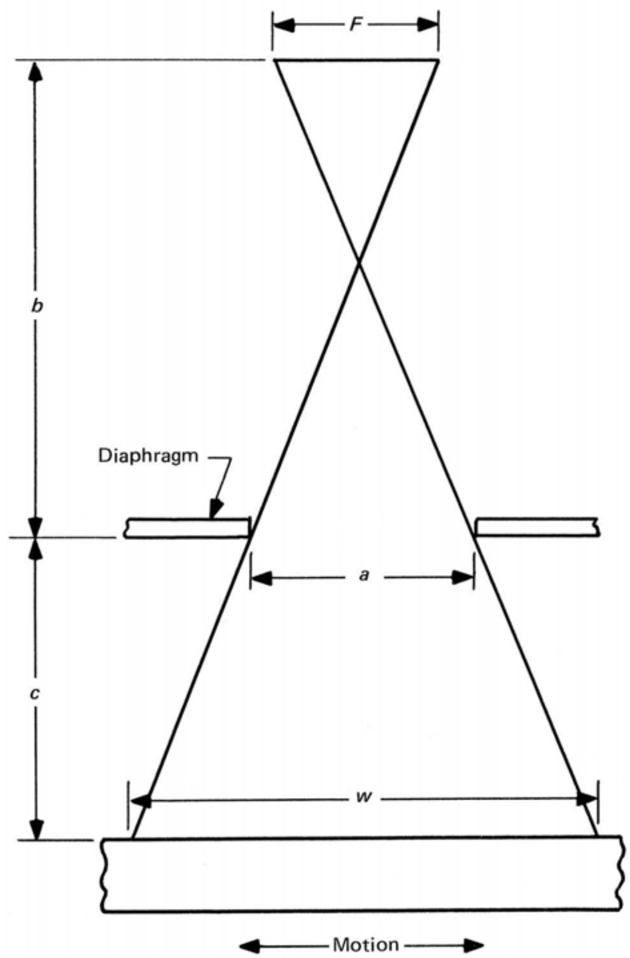
I-275 LOCATION MARKERS

Location markers shall be placed adjacent to the weld at the extremity of each film cassette and also at approximately equal intervals not exceeding 15 in. (381 mm).

I-277 PLACEMENT AND NUMBER OF IQIS

(a) For longitudinal welds, hole IQIs shall be placed adjacent to and on each side of the weld seam, or on the weld seam at the beginning and end of the weld seam,

Figure I-263
Beam Width Determination



and thereafter at approximately equal intervals not exceeding 36 in. (914 mm) or for each film cassette. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is across the length of the weld and spaced as indicated above for hole IQIs.

(b) For circumferential welds, hole IQIs shall be placed adjacent to and on each side of the weld seam or on the weld seam in each quadrant or spaced no greater than 36 in. (914 mm) apart, whichever is smaller. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is across the length of the weld and spaced as indicated above for hole IQIs.

I-279 REPAIRED AREA

When radiography of a repaired area is required, the length of the film used shall be at least equal to the length of the original location marker interval.

MANDATORY APPENDIX II
REAL-TIME RADIOSCOPIC EXAMINATION

II-210 SCOPE

Real-time radioscopy provides immediate response imaging with the capability to follow motion of the inspected part. This includes radioscopy where the motion of the test object must be limited (commonly referred to as near real-time radioscopy).

Real-time radioscopy may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein are satisfied. SE-1255 shall be used in conjunction with this Appendix as indicated by specific references in appropriate paragraphs. SE-1416 provides additional information that may be used for radioscopic examination of welds.

This Appendix is not applicable to film radiography, computed radiography (CR), or digital radiography (DR) techniques.

II-220 GENERAL REQUIREMENTS

This radioscopic methodology may be used for the examination of ferrous or nonferrous materials and weldments.

II-221 PROCEDURE REQUIREMENTS

A written procedure is required and shall contain as a minimum the following (see SE-1255, 5.2):

(a) material and thickness range
(b) equipment qualifications
(c) test object scan plan
(d) radioscopic parameters
(e) image processing parameters
(f) image display parameters
(g) image archiving

II-230 EQUIPMENT AND MATERIALS

II-231 RADIOSCOPIC EXAMINATION RECORD

The radioscopic examination data shall be recorded and stored on videotape, magnetic disk, or optical disk.

II-235 CALIBRATION BLOCK

The calibration block shall be made of the same material type and product form as the test object. The calibration block may be an actual test object or may be fabricated to simulate the test object with known discontinuities.

II-236 CALIBRATED LINE PAIR TEST PATTERN AND STEP WEDGE

The line pair test pattern shall be used without an additional absorber to evaluate the system resolution. The step wedge shall be used to evaluate system contrast sensitivity.

The step wedge must be made of the same material as the test object with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be inspected. Additional step thicknesses are permissible.

II-237 EQUIVALENT PERFORMANCE LEVEL

A system which exhibits a spatial resolution of 3 line pairs per millimeter, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% has an equivalent performance level of 3% — 2% — 3 lp/mm.

II-260 CALIBRATION

System calibration shall be performed in the static mode by satisfying the line pair test pattern resolution, step wedge contrast sensitivity, and calibration block discontinuity detection necessary to meet the IQI requirements of T-276.

II-263 SYSTEM PERFORMANCE MEASUREMENT

Real-time radioscopic system performance parameters shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at sufficiently scheduled intervals to minimize the probability of time-dependent performance variations. System performance tests require the use of the calibration block, line pair test pattern, and the step wedge.

System performance measurement techniques shall be standardized so that they may be readily duplicated at the specified intervals.

II-264 MEASUREMENT WITH A CALIBRATION BLOCK

The calibration block shall also be placed in the same position as the actual object and manipulated through the same range and speed of motions as will be used for the actual object to demonstrate the system's response in the dynamic mode.

II-270 EXAMINATION

II-278 SYSTEM CONFIGURATION

The radioscopic examination system shall, as a minimum, include the following:

(a) radiation source
(b) manipulation system
(c) detection system
(d) information processing system
(e) image display system
(f) record archiving system

II-280 EVALUATION

II-286 FACTORS AFFECTING SYSTEM PERFORMANCE

The radioscopic examination system performance quality is determined by the combined performance of the components specified in II-278. (See SE-1255, 6.1.)

When using wire IQIs, the radioscopic examination system may exhibit asymmetrical sensitivity, therefore, the wire diameter axis shall be oriented along the axis of the least sensitivity of the system.

II-290 DOCUMENTATION

II-291 RADIOSCOPIC TECHNIQUE INFORMATION

To aid in proper interpretation of the radioscopic examination data, details of the technique used shall accompany the data. As a minimum, the information shall include the items specified in T-291 when applicable, II-221, and the following:

(a) operator identification
(b) system performance test data

II-292 EVALUATION BY MANUFACTURER

Prior to being presented to the Inspector for acceptance, the examination data shall be interpreted by the Manufacturer as complying with the referencing Code Section. The Manufacturer shall record the interpretation and disposition of each weldment examined on a radiographic interpretation review form accompanying the radioscopic data.

MANDATORY APPENDIX III DIGITAL IMAGE ACQUISITION, DISPLAY, AND STORAGE FOR RADIOGRAPHY AND RADIOSCOPY

III-210 SCOPE

Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.

Digital imaging of all radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

III-220 GENERAL REQUIREMENTS

III-221 PROCEDURE REQUIREMENTS

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, and dynamic range

(b) image display parameters — format, contrast, and magnification

(c) image processing parameters that are used

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss)

(e) analog output formats

III-222 ORIGINAL IMAGE ARTIFACTS

Any artifacts that are identified in the original image shall be noted or annotated on the digital image.

III-230 EQUIPMENT AND MATERIALS

III-231 DIGITAL IMAGE EXAMINATION RECORD

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

III-234 VIEWING CONSIDERATIONS

The digital image shall be judged by visual comparison to be equivalent to the image quality of the original image at the time of digitization.

III-236 CALIBRATED OPTICAL LINE PAIR TEST PATTERN AND OPTICAL DENSITY STEP WEDGE

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. The optical density step wedge shall be used to evaluate system contrast sensitivity.

III-250 IMAGE ACQUISITION AND STORAGE

III-255 AREA OF INTEREST

Any portion of the image data may be digitized and stored provided the information that is digitized and stored includes the area of interest as defined by the referencing Code Section.

III-258 SYSTEM CONFIGURATION

The system shall, as a minimum, include the following:

(a) digitizing system

(b) display system

(c) image processing system

(d) image storage system

III-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity.

III-263 SYSTEM PERFORMANCE MEASUREMENT

System performance parameters (as noted in III-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

III-280 EVALUATION

III-286 FACTORS AFFECTING SYSTEM PERFORMANCE

The quality of system performance is determined by the combined performance of the components specified in III-258.

III-287 SYSTEM-INDUCED ARTIFACTS

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity in the original analog image.

III-290 DOCUMENTATION

III-291 DIGITAL IMAGING TECHNIQUE INFORMATION

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, and the following:

(a) operator identification

(b) system performance test data

III-292 EVALUATION BY MANUFACTURER

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopic image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digital examination data from a radiograph that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

MANDATORY APPENDIX IV INTERPRETATION, EVALUATION, AND DISPOSITION OF RADIOGRAPHIC AND RADIOSCOPIC EXAMINATION TEST RESULTS PRODUCED BY THE DIGITAL IMAGE ACQUISITION AND DISPLAY PROCESS

IV-210 SCOPE

The digital image examination test results produced in accordance with Article 2, Mandatory Appendix II, and Article 2, Mandatory Appendix III, may be interpreted and evaluated for final disposition in accordance with the additional provisions to Article 2 as indicated herein.

The digital information is obtained in series with radiography and in parallel with radioscopy. This data collection process also provides for interpretation, evaluation, and disposition of the examination test results.

IV-220 GENERAL REQUIREMENTS

The digital image shall be interpreted while displayed on the monitor. The interpretation may include density and contrast adjustment, quantification, and pixel measurement, including digital or optical density values and linear or area measurement.

The interpretation of a digitized image is dependent upon the same subjective evaluation by a trained interpreter as the interpretation of a radiographic or radioscopic image. Some of the significant parameters considered during interpretation include: area of interest, image quality, IQI image, magnification, density, contrast, discontinuity shape (rounded, linear, irregular), and artifact identification.

The digital image interpretation of the radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

After the interpretation has been completed, the interpretation data and the digital image, which shall include the unprocessed original full image and the digitally processed image, shall be recorded and stored on video tape, magnetic tape, or optical disk.

IV-221 PROCEDURE REQUIREMENTS

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, dynamic range, and pixel size;

(b) image display parameters — monitor size including display pixel size, luminosity, format, contrast, and magnification;

(c) signal processing parameters — including density shift, contrast stretch, log transform, and any other techniques that do not mathematically alter the original digital data, e.g., linear and area measurement, pixel sizing, and value determination;

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss). The non-erasable optical media should be used for archival applications. This is frequently called the WORM (Write Once Read Many) technology. When storage is accomplished on magnetic or erasable optical media, then procedures must be included that show trackable safeguards to prevent data tampering and guarantee data integrity.

IV-222 ORIGINAL IMAGE ARTIFACTS

Any artifacts that are identified shall be noted or annotated on the digital image.

IV-230 EQUIPMENT AND MATERIALS

IV-231 DIGITAL IMAGE EXAMINATION RECORD

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

IV-234 VIEWING CONSIDERATIONS

The digital image shall be evaluated using appropriate monitor luminosity, display techniques, and room lighting to insure proper visualization of detail.

IV-236 CALIBRATED OPTICAL LINE PAIR TEST PATTERN AND OPTICAL DENSITY STEP WEDGE

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. High spatial resolution with 14 line-pairs per millimeter (lp/mm) translates to a pixel size of 0.0014 in. (0.035 mm). Lesser spatial resolution with 2 lp/mm can be accomplished with a pixel size of 0.012 in. (0.3 mm). The optical density step wedge shall be used to evaluate system contrast sensitivity. Alternatively, a contrast sensitivity gage (step wedge block) in accordance with SE-1647 may be used.

IV-250 IMAGE ACQUISITION, STORAGE, AND INTERPRETATION

IV-255 AREA OF INTEREST

The evaluation of the digital image shall include all areas of the image defined as the area of interest by the referencing Code Section.

IV-258 SYSTEM CONFIGURATION

The system shall, as a minimum, include:

(a) digital image acquisition system

(b) display system

(c) image processing system

(d) image storage system

IV-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity. The electrical performance of the hardware and the quality of the digital image shall be measured and recorded.

IV-263 SYSTEM PERFORMANCE MEASUREMENT

System performance parameters (as noted in IV-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

IV-280 EVALUATION

IV-286 FACTORS AFFECTING SYSTEM PERFORMANCE

The quality of system performance is determined by the combined performance of the components specified in IV-258.

IV-287 SYSTEM-INDUCED ARTIFACTS

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity.

IV-290 DOCUMENTATION

IV-291 DIGITAL IMAGING TECHNIQUE INFORMATION

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, IV-221, IV-222, and the following:

(a) operator identification

(b) system performance test data

(c) calibration test data

IV-292 EVALUATION BY MANUFACTURER

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopic image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digitized examination data that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

MANDATORY APPENDIX VI ACQUISITION, DISPLAY, INTERPRETATION, AND STORAGE OF DIGITAL IMAGES OF RADIOGRAPHIC FILM FOR NUCLEAR APPLICATIONS

VI-210 SCOPE

Digital imaging process and technology provide the ability to digitize and store the detailed information contained in the radiographic film (analog image), thus eliminating the need to maintain and store radiographic film as the permanent record.

VI-220 GENERAL REQUIREMENTS

VI-221 SUPPLEMENTAL REQUIREMENTS

VI-221.1 Additional Information. Article 2, Mandatory Appendices III and IV, contain additional information that shall be used to supplement the requirements of this Appendix. These supplemental requirements shall be documented in the written procedure required by this Appendix.

VI-221.2 Reference Film. Supplement A contains requirements for the manufacture of the reference film.

VI-222 WRITTEN PROCEDURE

A written procedure is required. The written procedure shall be the responsibility of the owner of the radiographic film and shall be demonstrated to the satisfaction of the Authorized Nuclear Inspector (ANI). When other enforcement or regulatory agencies are involved, the agency approval is required by formal agreement. The written procedure shall include, as a minimum, the following essential variables:

VI-222.1 Digitizing System Description.

(a) manufacturer and model no. of digitizing system;
(b) physical size of the usable area of the image monitor;
(c) film size capacity of the scanning device;
(d) spot size(s) of the film scanning system;
(e) image display pixel size as defined by the vertical/horizontal resolution limits of the monitor;
(f) luminance of the video display; and
(g) data storage medium.

VI-222.2 Digitizing Technique.

(a) digitizer spot size (in microns) to be used (see VI-232);
(b) loss-less data compression technique, if used;
(c) method of image capture verification;
(d) image processing operations;
(e) time period for system verification (see VI-264);
(f) spatial resolution used (see VI-241);
(g) contrast sensitivity (density range obtained) (see VI-242);
(h) dynamic range used (see VI-243); and
(i) spatial linearity of the system (see VI-244).

VI-223 PERSONNEL REQUIREMENTS

Personnel shall be qualified as follows:

(a) Level II and Level III Personnel. Level II and Level III personnel shall be qualified in the radiographic method as required by Article 1. In addition, the employer's written practice shall describe the specific training and practical experience of Level II and Level III personnel involved in the application of the digital imaging process and the interpretation of results and acceptance of system performance. Training and experience shall be documented in the individual's certification records.

(b) As a minimum, Level II and III individuals shall have 40 hours of training and 1 month of practical experience in the digital imaging process technique.

(c) Other Personnel. Personnel with limited qualifications performing operations other than those required for the Level II or Level III shall be qualified in accordance with Article 1. Each individual shall have specified training and practical experience in the operations to be performed.

VI-230 EQUIPMENT AND MATERIALS

VI-231 SYSTEM FEATURES

The following features shall be common to all digital image processing systems:

(a) noninterlaced image display format;
(b) WORM — write-once/read-many data storage; and
(c) fully reversible (loss-less) data compression (if data compression is used).

VI-232 SYSTEM SPOT SIZE

The spot size of the digitizing system shall be:

(a) 70 microns or smaller for radiographic film exposed with energies up to 1 MeV; or

(b) 100 microns or smaller for radiographic film exposed with energies over 1 MeV.

VI-240 SYSTEM PERFORMANCE REQUIREMENTS

System performance shall be determined using the digitized representation of the reference targets (images). No adjustment shall be made to the digitizing system which may affect system performance after recording the reference targets.

VI-241 SPATIAL RESOLUTION

Spatial resolution shall be determined as described in VI-251. The system shall be capable of resolving a pattern of 7 line pairs/millimeter (lp/mm) for systems digitizing with a spot size of 70 microns or less, or 5 lp/mm for spot sizes greater than 70 microns.

VI-242 CONTRAST SENSITIVITY

Contrast sensitivity shall be determined as described in VI-252. The system shall have a minimum contrast sensitivity of 0.02 optical density.

VI-243 DYNAMIC RANGE

Dynamic range shall be determined as described in VI-253. The system shall have a minimum dynamic range of 3.5 optical density.

VI-244 SPATIAL LINEARITY

Spatial linearity shall be determined as described in VI-254. The system shall return measured dimensions with 3% of the actual dimensions on the reference film.

VI-250 TECHNIQUE

The reference film described in Supplement A and Figure VI-A-1 shall be used to determine the performance of the digitization system. The system settings shall be adjusted to optimize the display representation of the reference targets (images). The reference film and all subsequent radiographic film shall be scanned by the digitization system using these optimized settings.

VI-251 SPATIAL RESOLUTION EVALUATION

At least two of the converging line pair images (0 deg, 45 deg, and 90 deg line pairs) shall be selected near the opposite corners of the digitizing field and one image near the center of the digitized reference film. The spatial resolution in each position and for each orientation shall be recorded as the highest indicated spatial frequency (as determined by the reference lines provided) where all of the lighter lines are observed to be separated by the darker lines. The system resolution shall be reported as the poorest spatial resolution obtained from all of the resolution images evaluated.

VI-252 CONTRAST SENSITIVITY EVALUATION

Using the contrast sensitivity images and the digitized stepped density scale images to evaluate the detectability of each density step (the observed density changes shall be indicative of the system's capability to discern 0.02 density differences), the detectability of each density step and the difference in density between steps shall be evaluated.

VI-253 DYNAMIC RANGE EVALUATION

The dynamic range of the digitization system shall be determined by finding the last visible density step at both ends of the density strip. The dynamic range shall be measured to the nearest 0.50 optical density.

VI-254 SPATIAL LINEARITY EVALUATION

The digitization system shall be set to read the inch scale on the reference film. The measurement tool shall then be used to measure the scale in a vertical direction and horizontal direction. The actual dimension is divided by the measured dimension to find the percentage of error in the horizontal and vertical directions.

VI-260 DEMONSTRATION OF SYSTEM PERFORMANCE

VI-261 PROCEDURE DEMONSTRATION

The written procedure described in VI-222 shall be demonstrated to the ANI and, if requested, the regulatory agency, as having the ability to acquire, display, and reproduce the analog images from radiographic film. Evidence of the demonstration shall be recorded as required by VI-291.

VI-262 PROCESSED TARGETS

The digitizing process and equipment shall acquire and display the targets described in Supplement A. The digitally processed targets of the reference film shall be used to verify the system performance.

VI-263 CHANGES IN ESSENTIAL VARIABLES

Any change in the essential variables identified in VI-222 and used to produce the results in VI-250 shall be cause for reverification of the System Performance.

VI-264 FREQUENCY OF VERIFICATION

The System Performance shall be initially verified in accordance with VI-262 at the beginning of each digitizing shift. Reverification in accordance with VI-262 shall take place at the end of each shift or at the end of 12 continuous hours, whichever is less, or at any time that malfunctioning is suspected.

VI-265 CHANGES IN SYSTEM PERFORMANCE

Any evidence of change in the System Performance specified in VI-240 shall invalidate the digital images processed since the last successful verification and shall be cause for reverification.

VI-270 EXAMINATION

VI-271 SYSTEM PERFORMANCE REQUIREMENTS

The digitizing system shall meet the requirements specified in VI-240 before digitizing radiographic film.

VI-272 ARTIFACTS

Each radiographic film shall be visually examined for foreign material and artifacts (e.g., scratches or water spots) in the area of interest. Foreign material not removed and artifacts observed shall be documented.

VI-273 CALIBRATION

The calibration for a specific set of parameters (i.e., film size, density range, and spatial resolution) shall be conducted by following VI-240 and Supplement A. The results shall be documented.

VI-280 EVALUATION

VI-281 PROCESS EVALUATION

The Level II or Level III Examiner described in VI-223(a) shall be responsible for determining that the digital imaging process is capable of reproducing the original analog image. This digital image shall then be transferred to the write-once-read-many (WORM) optical disc.

VI-282 INTERPRETATION

When interpretation of the radiographic film is used for acceptance, the requirements of Article 2, Mandatory Appendix IV and the Referencing Code Section shall apply. When radiographic films must be viewed in composite for acceptance, then both films shall be digitized. The digital images of the films shall be interpreted singularly.

VI-283 BASELINE

Digital images of previously accepted radiographic film may be used as a baseline for subsequent in-service inspections.

VI-290 DOCUMENTATION

VI-291 REPORTING REQUIREMENTS

The following shall be documented in a final report:

(a) spatial resolution (VI-241);

(b) contrast sensitivity (VI-242);

(c) frequency for system verification;

(d) dynamic range (VI-243);

(e) Traceability technique from original component to film to displayed digital image, including original radiographic report(s). (The original radiographic reader sheet may be digitized to fulfill this requirement);

(f) condition of original radiographic film (VI-281);

(g) procedure demonstration (VI-261);

(h) spatial linearity (VI-244);

(i) system performance parameters (VI-241); and

(j) personnel performing the digital imaging process (VI-223).

VI-292 ARCHIVING

When the final report and digitized information are used to replace the radiographic film as the permanent record as required by the referencing Code Section, all information pertaining to the original radiography shall be documented in the final report and processed as part of the digital record. A duplicate copy of the WORM storage media is required if the radiographic films are to be destroyed.

MANDATORY APPENDIX VI
SUPPLEMENT A

VI-A-210 SCOPE

The reference film described in this supplement provides a set of targets suitable for evaluating and quantifying the performance characteristics of a radiographic digitizing system. The reference film is suitable for evaluating both the radiographic film digitization process and the electronic image reconstruction process.

The reference film shall be used to conduct performance demonstrations and evaluations of the digitizing system to verify the operating characteristics before radiographic film is digitized. The reference film provides for the evaluation of spatial resolution, contrast sensitivity, dynamic range, and spatial linearity.

VI-A-220 GENERAL

VI-A-221 REFERENCE FILM

The reference film shall be specified in VI-A-230 and VI-A-240.

VI-A-230 EQUIPMENT AND MATERIALS

VI-A-231 REFERENCE TARGETS

The illustration of the reference film and its targets is as shown in Figure VI-A-1.

VI-A-232 SPATIAL RESOLUTION TARGETS

The reference film shall contain spatial resolution targets as follows:

VI-A-232.1 Converging Line Pair Targets. Converging line pairs shall consist of 3 identical groups of no less than 6 converging line pairs (6 light lines and 6 dark lines). The targets shall have a maximum resolution of no less than 20 line pairs per millimeter (lp/mm) and a minimum resolution of no greater than 1 lp/mm. The 3 line pair groups shall be oriented in the vertical, horizontal, and the last group shall be 45 deg from the previous two groups. The maximum resolution shall be oriented toward the corners of the film. Reference marks shall be provided to indicate spatial resolution at levels of no less than 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/mm. The spatial resolution targets shall be located in each corner of the needed film sizes.

VI-A-232.2 Parallel Line Pair Targets. Parallel line pairs shall consist of parallel line pairs in at least the vertical direction on the reference film. It shall have a maximum resolution of at least 20 lp/mm and a minimum resolution of no less than 0.5 lp/mm. It shall have distinct resolutions of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/mm and have the corresponding reference marks. It shall be located near the middle of the reference film.

VI-A-233 CONSTRAST SENSITIVITY TARGETS

Contrast sensitivity targets shall consist of approximately 0.4 in. × 0.4 in. (10 mm × 10 mm) blocks centered in 1.6 in. × 1.6 in. (40 mm × 40 mm) blocks of a slightly lower density. Two series of these step blocks shall be used with an optical density of approximately 2.0 on a background of approximately 1.95, an optical density change of 0.05. The second block series will have an optical density of approximately 3.5 on a background of approximately 3.4, an optical density change of 0.10. The relative density change is more important than the absolute density. These images shall be located near the edges and the center of the film so as to test the contrast sensitivity throughout the scan path.

VI-A-234 DYNAMIC RANGE TARGETS

Stepped density targets shall consist of a series of 0.4 in. × 0.4 in. (10 mm × 10 mm) steps aligned in a row with densities ranging from 0.5 to 4.5 with no greater than 0.5 optical density steps. At four places on the density strip (at approximately 1.0, 2.0, 3.0, and 4.0 optical densities), there shall be optical density changes of 0.02 which shall also be used to test the contrast sensitivity. These stepped density targets shall be located near the edges of the film and near the center so as to test the dynamic range throughout the scan path.

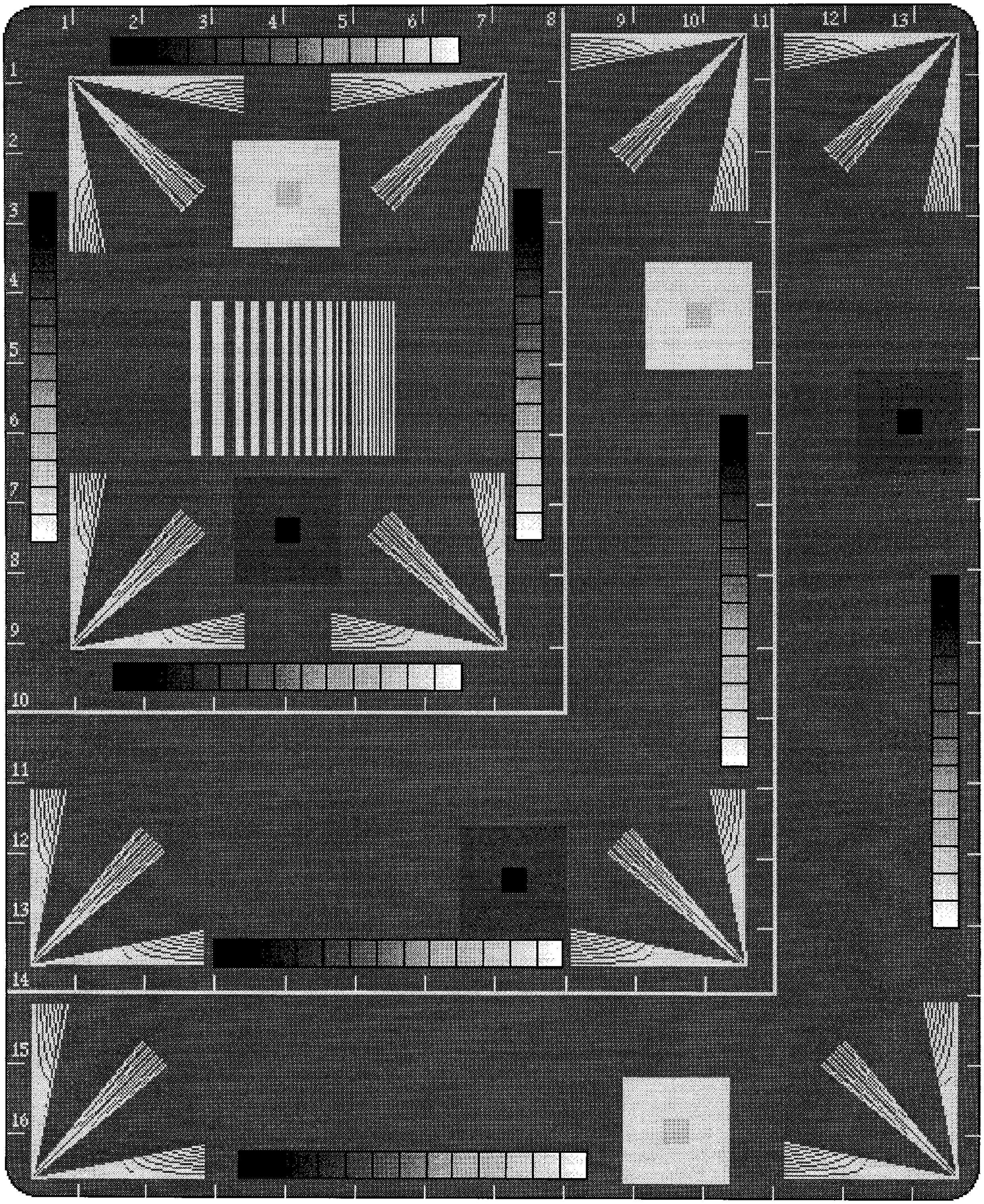
VI-A-235 SPATIAL LINEARITY TARGETS

Measurement scale targets shall be located in the horizontal and vertical dimensions. The measurement scale targets shall be in English and/or metric divisions.

VI-A-240 MISCELLANEOUS REQUIREMENTS

Manufacturing specifications shall be minimum requirements necessary for producing the reference film. The reference film shall have a unique identification which appears as an image when digitized.

Figure VI-A-1
Reference Film



VI-A-241 MATERIAL

The reference film shall be a fine grain, industrial type film. The film used will be of high quality so the required specifications in VI-A-230 are met.

VI-A-242 FILM SIZE

The film size shall be sufficient to accommodate the largest area of interest to be digitized.

VI-A-243 SPATIAL RESOLUTION

The spatial resolution shall be a minimum of 20 lp/mm.

VI-A-244 DENSITY

The relative densities stated in VI-A-233 and VI-A-234 shall be ±0.005 optical density.

(a) The tolerance for the optical density changes stated in VI-A-233 and VI-A-234 shall be ±0.005.

(b) The measured densities shall be ±0.15 of the values stated in VI-A-233 and VI-A-234. The actual densities shall be recorded and furnished with the reference film.

(c) Density requirements shall be in accordance with ANSI IT-2.19.

(d) The background density, where there are no images located, shall have a 3.0 optical density ±0.5.

VI-A-245 LINEARITY

The measurement scale targets shall be accurately electronically produced to ±0.05 in. (±1.3 mm).

MANDATORY APPENDIX VII RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

VII-210 SCOPE

Metallic castings, due to their inherent complex configurations, present examination conditions that are unique to this product form.

Radiographic examination may be performed on castings when the modified provisions to Article 2, as indicated herein, are satisfied.

VII-220 GENERAL REQUIREMENTS

VII-224 SYSTEM OF IDENTIFICATION

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, or part numbers, as appropriate. In addition, each film of a casting being radiographed shall be plainly and permanently identified with the name or symbol of the Material Manufacturer, Certificate Holder, or Subcontractor, job or heat number, date, and, if applicable, repairs (R1, R2, etc.). This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

VII-270 EXAMINATION

VII-271 RADIOGRAPHIC TECHNIQUE

VII-271.2 Double-Wall Viewing Technique. A double-wall viewing technique may be used for cylindrical castings $3^1/_2$ in. (89 mm) or less in O.D. or when the shape of a casting precludes single-wall viewing.

VII-276 IQI SELECTION

VII-276.3 Additional IQI Selection Requirements. The thickness on which the IQI is based is the single-wall thickness.

(a) Casting Areas Prior to Finish Machining. The IQI shall be based on a thickness that does not exceed the finished thickness by more than 20% or $^1/_4$ in. (6 mm), whichever is greater. In no case shall an IQI size be based on a thickness greater than the thickness being radiographed.

(b) Casting Areas That Will Remain in the As-Cast Condition. The IQI shall be based on the thickness being radiographed.

VII-280 EVALUATION

VII-282 RADIOGRAPHIC DENSITY

VII-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole-type IQI adjacent to the essential hole or adjacent to the essential wire of a wire-type IQI and the area of interest shall be 1.5 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

VII-290 DOCUMENTATION

VII-293 LAYOUT DETAILS[7]

To assure that all castings are radiographed consistently in the same manner, layout details shall be provided. As a minimum, the layout details shall include:

(a) sketches of the casting, in as many views as necessary, to show the approximate position of each location marker; and

(b) source angles if not perpendicular to the film.

MANDATORY APPENDIX VIII
RADIOGRAPHY USING PHOSPHOR IMAGING PLATE

VIII-210 SCOPE

This Appendix provides requirements for using phosphor imaging plate (photostimulable luminescent phosphor) as an alternative to film radiography.

Radiography using phosphor imaging plate may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein and all other requirements of Article 2 are satisfied. The term *film*, as used within Article 2, applicable to performing radiography in accordance with this Appendix, refers to phosphor imaging plate. ASTM E2007, *Standard Guide for Computed Radiography,* may be used as a guide for general tutorial information regarding the fundamental and physical principles of computed radiography (CR), including some of the limitations of the process.

VIII-220 GENERAL REQUIREMENTS

VIII-221 PROCEDURE REQUIREMENTS

(**19**) **VIII-221.1 Written Procedure.** A written procedure is required. In lieu of the requirements of T-221.1, each procedure shall include at least the following information, as applicable:

(a) material type and thickness range

(b) isotope or maximum X-ray voltage used

(c) minimum source-to-object distance (*D* in T-274.1)

(d) distance from source side of object to the phosphor imaging plate (*d* in T-274.1)

(e) source size (*F* in T-274.1)

(f) phosphor imaging plate manufacturer and designation

(g) screens used

(h) image scanning and processing equipment manufacturer and model

(i) image scanning parameters (i.e., gain, laser resolution), detailed, as applicable, for material thicknesses across the thickness range

(j) pixel intensity/gray range (minimum to maximum)

(**19**) **VIII-221.2 Procedure Demonstration.** A demonstration shall be required at the minimum and maximum material thicknesses stated in the procedure. Procedure demonstration details and demonstration block requirements are described in Supplement A of this Appendix.

VIII-225 MONITORING DENSITY LIMITATIONS OF RADIOGRAPHS

The requirements of T-225 are not applicable to phosphor imaging plate radiography.

VIII-230 EQUIPMENT AND MATERIALS

VIII-231 PHOSPHOR IMAGING PLATE

VIII-231.1 Selection. Radiography shall be performed using an industrial phosphor imaging plate capable of demonstrating IQI image requirements.

VIII-231.2 Processing. The system used for processing a phosphor imaging plate shall be capable of acquiring, storing, and displaying the digital image.

VIII-234 FACILITIES FOR VIEWING OF RADIOGRAPHS

Viewing facilities shall provide subdued background lighting of an intensity that will not cause reflections, shadows, or glare on the monitor that interfere with the interpretation process.

VIII-260 CALIBRATION

VIII-262 DENSITOMETER AND STEP WEDGE COMPARISON FILM

The requirements of T-262 are not applicable to phosphor imaging plate radiography.

VIII-270 EXAMINATION

VIII-277 USE OF IQIS TO MONITOR RADIOGRAPHIC EXAMINATION

VIII-277.1 Placement of IQIs.

(a) Source-Side IQI(s). When using separate blocks for IQI placement as described in T-277.1(a), the thickness of the blocks shall be such that the image brightness at the body of the IQI is judged to be equal to or greater than the image brightness at the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 2% are permitted in the determination of "equal to." This image brightness requirement is reversed for a positive image format.

(b) All other requirements of T-277.1 shall apply.

VIII-277.2 Number of IQIs.

(a) Multiple IQIs. An IQI shall be used for each applicable thickness range in Table T-276 spanned by the minimum-to-maximum thickness of the area of interest to be radiographed.

(b) As an alternative to (a) above, a minimum of two IQIs representing the minimum and maximum thicknesses of the area of interest may be used, provided the requirements of VIII-288 are met.

(c) All other requirements of T-277.2 shall apply.

(d) Comparators such as digitized film strips, gray scale cards, etc., may be used to aid in judging displayed image brightness. When comparators are used to judge areas within the image, they need not be calibrated. Pixel intensity values may also be used to quantify image brightness comparisons.

VIII-277.3 Shims Under Hole IQIs. For welds with reinforcement or backing material, a shim of material radiographically similar to the weld metal and/or backing material shall be placed between the part and the IQIs, such that the image brightness at the body of the IQI is judged to be equal to or greater than the image brightness at the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 2% are permitted in the determination of "equal to." This image brightness requirement is reversed for a positive image format.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI shall be visible in the radiograph.

VIII-280 EVALUATION

VIII-281 SYSTEM-INDUCED ARTIFACTS

The digital image shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity.

VIII-282 IMAGE BRIGHTNESS

The image brightness through the body of the hole-type IQI or adjacent to the designated wire of the wire-type IQI, shall be judged to be equal to or greater than the image brightness in the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 2% are permitted in the determination of "equal to." This image brightness requirement is reversed for a positive image format. Additionally, the requirements of T-282 are not applicable to phosphor imaging plate radiography.

VIII-283 IQI SENSITIVITY

(19) **VIII-283.1 Required Sensitivity.** Radiography shall be performed with a technique of sufficient sensitivity to display the designated hole-type IQI image and the essential hole, or the essential wire of a wire-type IQI. The radiographs shall also display the IQI identifying numbers and letters. Multiple film technique is not applicable to phosphor imaging plate radiography.

For wire-type IQIs, the essential wire shall be visible within the area of interest representing the thickness used for determining the essential wire, inclusive of the allowable brightness variations described in VIII-282.

VIII-284 EXCESSIVE BACKSCATTER

For a negative image format, the requirements of T-284 shall apply. For a positive image format, if a dark image of the "B," as described in T-223, appears on a lighter background of the image, protection from backscatter is insufficient and the radiographic image shall be considered unacceptable. A light image of the "B" on a darker background is not cause for rejection.

VIII-287 DIMENSIONAL MEASURING

VIII-287.1 Measuring Scale Comparator. The measuring scale used for interpretation shall be capable of providing dimensions of the projected image. The measurement scale tool shall be based on one of the following:

(a) a known dimensional comparator that is placed in direct contact with the cassette prior to exposure

(b) a known dimensional comparator that is inscribed on the imaging plate prior to processing

(c) a known comparator scale placed on the imaging plate prior to processing

VIII-287.2 Alternative Comparator. As an alternative to a measuring scale comparator, a dimensional calibration of the measuring function based upon a verifiable scanned pixel size may be used.

VIII-288 INTERPRETATION

Prior to interpretation, the range of contrast/brightness values that demonstrate the required IQI sensitivity shall be determined. Final radiographic interpretation shall be made only after the data within this IQI sensitivity range has been evaluated. The IQI and the area of interest shall be of the same image format (positive or negative). Additionally, where applicable

(a) when more than one IQI is used to qualify a range of thicknesses, the overlapping portions of each IQI's established sensitivity range shall be considered valid for interpretation of intervening thicknesses.

(b) the digital image may be viewed and evaluated in a negative or positive image format.

(c) independent areas of interest of the same image may be displayed and evaluated in differing image formats, provided the IQI and the area of interest are viewed and evaluated in the same image format.

VIII-290 DOCUMENTATION

VIII-291 DIGITAL IMAGING TECHNIQUE DOCUMENTATION DETAILS

The organization shall prepare and document the radiographic technique details. As a minimum, the following information shall be provided:

(a) the requirements of Article 1, T-190(a)

(b) identification as required by T-224

(c) the dimensional map (if used) of marker placement in accordance with T-275.3

(d) number of exposures

(e) X-ray voltage or isotope used

(f) source size (F in T-274.1)

(g) base material type and thickness, weld reinforcement thickness, as applicable

(h) source-to-object distance (D in T-274.1)

(i) distance from source side of object to storage phosphor media (d in T-274.1)

(j) storage phosphor manufacturer and designation

(k) image acquisition (digitizing) equipment manufacturer, model, and serial number

(l) single- or double-wall exposure

(m) single- or double-wall viewing

(n) procedure identification and revision level

(o) imaging software version and revision

(p) numerical values of the final image processing parameters, to include filters, window (contrast), and level (brightness) for each view

The technique details may be embedded in the data file. When this is performed, ASTM E1475, Standard Guide for Data Fields for Computerized Transfer of Digital Radiological Test Data, may be used as a guide for establishing data fields and information content.

(19)

MANDATORY APPENDIX VIII SUPPLEMENT A

VIII-A-210 SCOPE

This Supplement provides the details and requirements for procedure demonstrations in accordance with Mandatory Appendix VIII, VIII-221.2. This Supplement shall be used to demonstrate the ability to produce an acceptable image in accordance with the requirements of the written procedure.

VIII-A-220 GENERAL

VIII-A-221 DEMONSTRATION BLOCK

The demonstration block shall meet the requirements of Figure VIII-A-221-1 and shall be of material that is radiographically similar to the material described in the procedure.

(a) A minimum of two demonstration blocks, representing the minimum and maximum thicknesses of the procedure thickness range, shall be required for procedure qualification.

(b) Additional blocks may be used to validate specific parameters at intermediate thicknesses throughout the total thickness range.

(c) As an alternative to (a) and (b), one demonstration block containing a series of embedded notches of different depths may be used with shim plates of appropriate thicknesses to provide demonstration of both the minimum and maximum thicknesses to be qualified for the procedure.

VIII-A-230 EQUIPMENT AND MATERIALS

VIII-A-231 SCAN PARAMETERS

The scanning parameters used to acquire the radiographic image shall be verifiable, embedded in the image data or associated header metadata information or recorded on the radiographic detail sheet.

VIII-A-232 GRAY SCALE VALUES

The pixel intensity values in the region of interest shall fall within the minimum/maximum values described in the procedure. These pixel intensity values shall be based on actual assigned image bitmap values, not digital drive levels.

VIII-A-233 IMAGE QUALITY INDICATORS

The designated image quality indicators (IQIs) used for the demonstration shall be selected from Table T-276. All IQIs used shall meet the requirements of T-233.

VIII-A-240 MISCELLANEOUS REQUIREMENTS

The radiographic image of the demonstration block shall be viewed and evaluated without the aid of post-processing filters. Image analysis shall be performed through window and level (brightness and contrast) variation only.

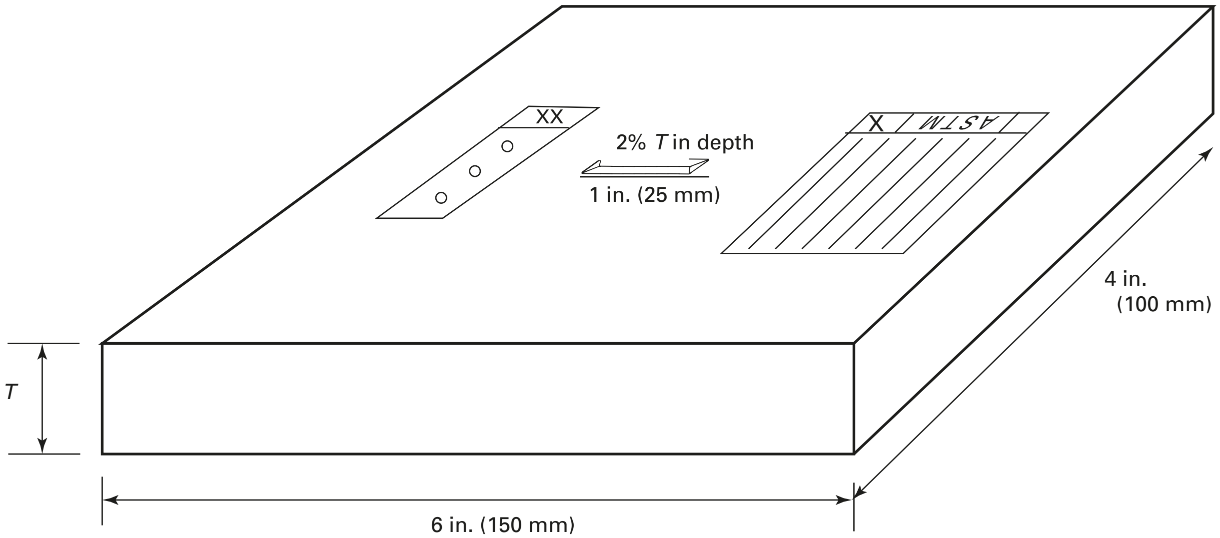
VIII-A-241 SENSITIVITY

As a minimum, both IQIs (essential wire and designated hole) shall be visible while the embedded notch is discernable. This shall be accomplished in raw data, without the aid of processing algorithms or filters.

VIII-A-242 RECORDS

The raw, unfiltered images of the procedure demonstration shall be maintained and available for review. The images shall be clearly identified and traceable to the procedure for which they are used for qualification.

Figure VIII-A-221-1
Procedure Demonstration Block



GENERAL NOTES:

(a) Hole-type and wire-type IQIs shall be selected as appropriate for *T* from Table T-276. Notch depth need not be less than 0.005 in. (0.13 mm).

(b) The 4-in. and 6-in. block dimensions are a minimum. The block dimensions may be increased appropriately as *T* increases.

(c) Notch dimensions shall be as follows:

depth = 1.6%*T* to 2.2%*T*

width = 0.5 in. (13 mm) and less, *T* shall be 2 times the notch depth; above 0.5 in. (13 mm) through 1 in. (25 mm), *T* shall be 1.5 times the notch depth; above 1 in. (25 mm), *T* shall be equal to notch depth

length = 1 in. (25 mm)

(d) Notch location shall be approximately center of the demonstration block.

MANDATORY APPENDIX IX
RADIOGRAPHY USING DIGITAL DETECTOR SYSTEMS

IX-210 SCOPE

This Appendix provides requirements for the use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. This Appendix addresses applications in which the radiation detector, the source of the radiation, and the object being radiographed may or may not be in motion during exposure. Article 2 provisions apply unless modified by this Appendix.

IX-220 GENERAL REQUIREMENTS

References to a Standard contained within this Appendix apply only to the extent specified in that paragraph.

IX-221 PROCEDURE REQUIREMENTS

(19) **IX-221.1 Written Procedure.** A written procedure is required. In lieu of the requirements of T-221.1, each procedure shall contain the following requirements as applicable:

(a) material type and thickness range
(b) isotope or maximum X-ray voltage used
(c) detector type, manufacturer, and model
(d) minimum source-to-object distance (*D* in T-274.1)
(e) distance from source side of object to the detector (*d* in T-274.1)
(f) focal size (*F* in T-274.1)
(g) image display parameters
(h) storage media
(i) radiation filters/masking
(j) detector/source alignment validation
(k) pixel intensity/gray range (minimum to maximum)
(l) frame averaging

(19) **IX-221.2 Procedure Demonstration.** A demonstration shall be required at the minimum and maximum material thicknesses stated in the procedure. Procedure demonstration details and demonstration block requirements are described in Supplement A of this Appendix.

IX-225 MONITORING DENSITY LIMITATIONS OF RADIOGRAPHS

The requirements of T-225 are not applicable to direct radiography.

IX-230 EQUIPMENT AND MATERIALS

IX-231 FILM

The requirements of T-231 are not applicable to direct radiography.

IX-232 INTENSIFYING SCREENS

The requirements of T-232 are not applicable to direct radiography.

IX-234 FACILITIES FOR VIEWING OF RADIOGRAPHS

Viewing facilities shall provide subdued background lighting of an intensity that will not cause reflections, shadows, or glare on the monitor that interfere with the interpretation process.

IX-260 CALIBRATION

All DDSs require, after readout, a software-based calibration to determine the underperforming pixel map in accordance with manufacturer's guidelines. Calibration software shall be capable of correcting the nonuniformities as defined in ASTM E2597, Standard Practice for Manufacturing Characterization of Digital Detector Arrays.

Calibration is required for the following:

(a) at the commencement of the qualification of each examination procedure

(b) change in material

(c) change in quantity and/or energy of radiation (voltage, current, isotope)

(d) change in equipment used

(e) temperature variance in accordance with manufacturer's guidelines

(f) change in technique parameters

(g) failure to achieve the image quality requirements

IX-262 DENSITOMETER AND STEP WEDGE COMPARISON FILM

The requirements of T-262 are not applicable to direct radiography.

IX-263 BEAM WIDTH

When a change in motion of the source, detector, travel speed, or any combination of these occurs, the beam width shall be controlled by a metal diaphragm such as lead. The diaphragm for the energy selected shall be at least 10 half value layers thick.

The beam width as shown in Figure IX-263 shall be determined in accordance with

$$w = \frac{c(F + a)}{b} + a$$

where

- a = slit width in diaphragm in the direction of motion
- b = distance from source to the material/weld side of the diaphragm
- c = distance from material/weld side of the diaphragm to the source side of the material/weld surface
- F = source size: the maximum projected dimension of the radiating source (or focal spot) in the plane perpendicular to the distance $b + c$ from the material/weld being radiographed
- w = beam width at the source side of the material/weld measured in the direction of motion

IX-270 EXAMINATION

IX-274 GEOMETRIC AND IN-MOTION UNSHARPNESS

IX-274.1 Geometric Unsharpness. Recommended geometric unsharpness shall be determined in accordance with T-274.1.

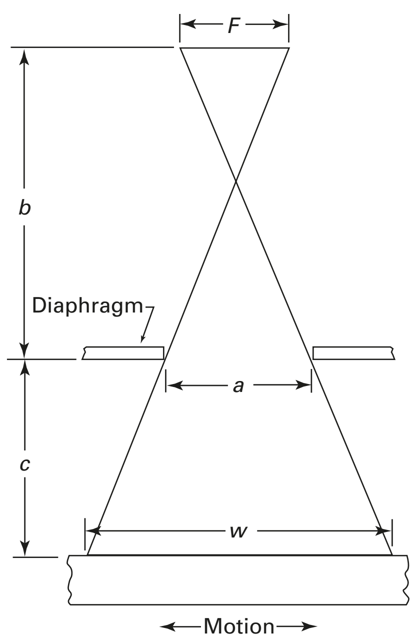
IX-274.2 In-Motion Unsharpness. In-motion unsharpness of the radiograph shall be determined in accordance with

$$U_M = \frac{wd}{D}$$

where

- D = distance from source of radiation to material/weld being radiographed
- d = distance from source side of the material/weld being radiographed to the film
- UM = in-motion unsharpness
- w = beam width at the source side of the material/weld measured in the direction of motion determined as specified in IX-263

Figure IX-263
Beam Width Determination



IX-275 LOCATION MARKERS

(a) When encoders are used for in-motion applications, location markers are not required. A calibration check shall be performed to verify that the displayed distance does not exceed ±1% of the actual distance moved.

(b) When encoders are not used, the requirements of T-275 shall apply.

IX-277 USE OF IQIS TO MONITOR RADIOGRAPHIC EXAMINATION

(19) **IX-277.1 Placement of IQIs.**

(a) Source-Side IQI(s). When using separate blocks for IQI placement as described in T-277.1(a), the thickness of the blocks shall be such that the image brightness at the body of the IQI is judged to be equal to or greater than the image brightness at the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 2% are permitted in the determination of "equal to." This image brightness requirement is reversed for a positive image format.

(b) For longitudinal welds examined using an in-motion technique, hole IQIs shall be placed adjacent to and on each side of the weld seam, or on the weld seam at the beginning and end of the weld seam, and thereafter at approximately equal intervals not exceeding 36 in. (914 mm). Wire IQIs, when used, shall be placed across the weld seam at an angle that is approximately between 2 deg and 5 deg to the rows/columns of the detector and spaced as indicated above for hole IQIs.

(c) For circumferential welds examined using an in-motion technique, hole IQIs shall be placed adjacent to and on each side of the weld seam or on the weld seam in each quadrant or spaced no greater than 36 in. (914 mm) apart, whichever is smaller. Wire IQIs, when used, shall be placed across the weld seam at an angle that is approximately between 2 deg and 5 deg to the rows/columns of the detector and spaced as indicated above for hole IQIs.

(d) For in-motion techniques, the IQI may be placed above the surface of the pipe or held in position between the surface of the pipe and the imager by a fixture attached to the imager or scanning device. Acceptability of such IQI placement shall be demonstrated during procedure qualification.

(e) All other requirements of T-277.1 shall apply.

IX-277.2 Number of IQIs.

(a) Multiple IQIs. An IQI shall be used for each applicable thickness range in Table T-276 spanned by the minimum-to-maximum thickness of the area of interest to be radiographed.

(b) As an alternative to (a) above, a minimum of two IQIs representing the minimum and maximum thicknesses of the area of interest may be used, provided the requirements of IX-288 are met.

(c) All other requirements of T-277.2 shall apply.

IX-277.3 Shims Under Hole-Type IQIs. For welds with reinforcement or backing material, a shim of material radiographically similar to the weld metal and/or backing material shall be placed between the part and the IQIs such that the image brightness at the body of the IQI is judged to be equal to or greater than the image brightness at the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 2% are permitted in the determination of "equal to." This image brightness requirement is reversed for a positive image format.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI is visible in the radiograph.

IX-280 EVALUATION

IX-281 QUALITY OF DIGITAL IMAGES

IX-281.1 Underperforming Pixel Display. Bad pixels are underperforming detector elements and shall be addressed as follows: (19)

(a) DDSs using static detectors shall not have cluster kernel pixels (CKPs) in the area of interest. An overlay may be used for verification. Refer to ASME SE-2597.

(b) For DDSs that use multiple overlapping pixel data arrangements, CKPs are not relevant provided acquired image data does not mask a relevant indication or create an image artifact.

IX-281.2 System-Induced Artifacts. The relevance of underperforming pixels shall be evaluated. The digital image shall be free of system-induced artifacts, such as underperforming pixels in the detector in the area of interest that could mask or be confused with the image of any discontinuity.

IX-282 IMAGE BRIGHTNESS

The image brightness through the body of the hole-type IQI or adjacent to the designated wire of the wire-type IQI, shall be judged to be equal to or greater than the image brightness in the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 2% are permitted in the determination of "equal to." This image brightness requirement is reversed for a positive image format. Additionally, the requirements of T-282 are not applicable to direct radiography.

IX-283 IQI SENSITIVITY

IX-283.1 Required Sensitivity. Radiography shall be performed with a technique of sufficient sensitivity to display the designated hole-type IQI image and the essential hole, or the essential wire of a wire-type IQI. The radiographs shall also display the IQI identifying numbers and letters. (19)

For wire-type IQIs, the essential wire shall be visible within the area of interest representing the thickness used for determining the essential wire, inclusive of the allowable brightness variations described in IX-282.

IX-284 EXCESSIVE BACKSCATTER

For a negative image format, the requirements of T-284 shall apply. For a positive image format, if a dark image of the "B," as described in T-223, appears on a lighter background of the image, protection from backscatter is insufficient and the radiographic image shall be considered unacceptable. A light image of the "B" on a darker background is not cause for rejection.

A test to determine if backscatter is present shall be performed by making an exposure where a lead filter is placed on one half of the backside of the digital detector array (DDA) exposed to radiation. A second exposure shall be made, with the lead moved to the other half of the DDA. If presence of backscatter is detected, the back of the detector shall be shielded and the test repeated.

IX-287 DIMENSIONAL MEASURING

IX-287.1 Measuring Scale Comparator. The measuring scale used for interpretation shall be capable of providing dimensions of the projected image. The measurement scale tool shall be based upon a known dimensional comparator that is placed on or adjacent to the detector side of the part near the area of interest during exposure.

IX-287.2 Alternative Comparator. As an alternative to a measuring scale comparator, a dimensional calibration of the measuring function based upon the detector pixel size may be used.

IX-288 INTERPRETATION

Interpretation of the area of interest shall be performed only after determining the minimum contrast/brightness values and the maximum contrast/brightness values that demonstrate the required IQI sensitivity. Final radiographic interpretation shall be made only after the data within this IQI sensitivity range has been evaluated.

Additionally, where applicable

(a) When more than one IQI is used to qualify multiple thicknesses, the overlapping portions of each IQI's established sensitivity range shall be considered valid for interpretation of intervening thicknesses.

(b) the digital image may be viewed and evaluated in a negative or positive image format.

(c) independent areas of interest of the same image may be displayed and evaluated in differing image formats, provided the IQI and the area of interest are viewed and evaluated in the same image format.

IX-290 DOCUMENTATION

IX-291 DIGITAL IMAGING TECHNIQUE DOCUMENTATION DETAILS

The organization shall prepare and document the radiographic technique details. As a minimum, the following information shall be provided:

(a) the requirements of Article 1, T-190(a)
(b) identification as required by T-224
(c) the dimensional map (if used) of marker placement in accordance with T-275.3
(d) the min./max. travel speed of the detector, source of radiation, and/or test object
(e) X-ray voltage or isotope used
(f) focal size (*F* in T-274.1)
(g) base material type and thickness, weld reinforcement thickness, as applicable
(h) source-to-object distance (*D* in T-274.1)
(i) distance from source side of object to the detector (*d* in T-274.1)
(j) detector manufacturer, designation, and serial number
(k) image acquisition (digitizing) equipment and manufacturer, model, and serial number
(l) single- or double-wall exposure
(m) single- or double-wall viewing
(n) procedure identification and revision level
(o) imaging software version and revision
(p) numerical values of the final image processing parameters, to include filters, window (contrast), and level (brightness) for each view
(q) underperforming pixel evaluation for each image
(r) computer monitor resolution

The technique details may be embedded in the data file. When this is performed, ASTM E1475, Standard Guide for Data Fields for Computerized Transfer of Digital Radiological Test Data, may be used as a guide for establishing data fields and information content.

(19)

MANDATORY APPENDIX IX SUPPLEMENT A

IX-A-210 SCOPE

This Supplement provides the details and requirements for procedure demonstrations in accordance with Mandatory Appendix IX, IX-221.2. This Supplement shall be used to demonstrate the ability to produce an acceptable image in accordance with the requirements of the written procedure.

IX-A-220 GENERAL

IX-A-221 DEMONSTRATION BLOCK

The demonstration block shall meet the requirements of Mandatory Appendix VIII, Supplement A, Figure VIII-A-221-1 and shall be of material that is radiographically similar to the material described in the procedure.

(a) A minimum of two demonstration blocks, representing the minimum and maximum thicknesses of the procedure thickness range, shall be required for procedure qualification.

(b) Additional blocks may be used to validate specific parameters at intermediate thicknesses throughout the total thickness range.

(c) As an alternative to (a) and (b), one block containing a series of embedded notches of different depths may be used with shim plates of appropriate thicknesses to provide demonstration of both the minimum and maximum thicknesses to be qualified for the procedure.

For in-motion procedures, pipe, rolled plate, or other suitable product forms may be used to accommodate radiation devices, transport mechanisms, and related fixturing as necessary in order to replicate procedure application variables.

IX-A-230 EQUIPMENT AND MATERIALS

IX-A-231 ACQUISITION PARAMETERS

The acquisition parameters used to acquire the radiographic image shall be verifiable, either embedded in the image data or in the associated header metadata information or recorded on the radiographic detail sheet.

IX-A-232 GRAY SCALE VALUES

The pixel intensity values in the region of interest shall fall within the minimum/maximum values described in the procedure. The pixel intensity values will be based on actual assigned image bitmap values, not digital drive levels.

IX-A-233 IMAGE QUALITY INDICATORS

The designated image quality indicators (IQIs) used for the demonstration shall be selected from Table T-276. All IQIs used shall meet the requirements of T-233.

IX-A-240 MISCELLANEOUS REQUIREMENTS

The radiographic image of the demonstration block shall be viewed and evaluated without the aid of post-processing filters. Image analysis shall be performed through window and level (brightness and contrast) variation only.

IX-A-241 SENSITIVITY

As a minimum, both IQIs (essential wire and designated hole) shall be visible while the embedded notch is discernable. This shall be accomplished in raw data, without the aid of processing algorithms or filters.

IX-A-242 RECORDS

The raw, unfiltered images of the procedure demonstration shall be maintained and available for review. The images shall be clearly identified and traceable to the procedure for which they are used for qualification.

NONMANDATORY APPENDIX A
RECOMMENDED RADIOGRAPHIC TECHNIQUE SKETCHES FOR PIPE OR TUBE WELDS

A-210 SCOPE

The sketches in Figures A-210-1 and A-210-2 of this Appendix illustrate techniques used in the radiographic examination of pipe or tube welds. Other techniques may be used.

Figure A-210-1
Single-Wall Radiographic Techniques

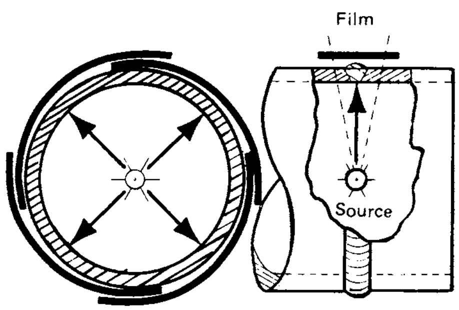
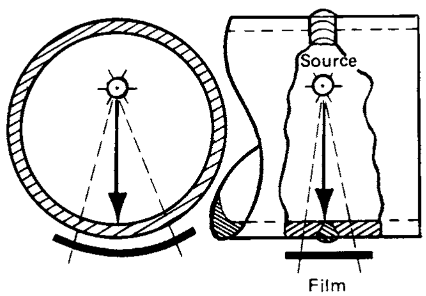
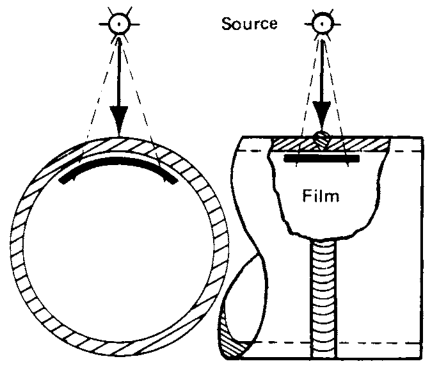
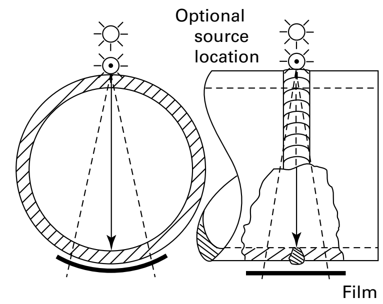
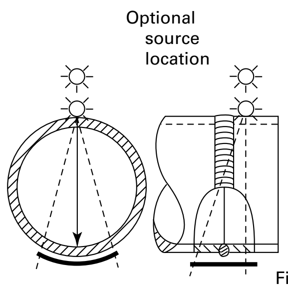
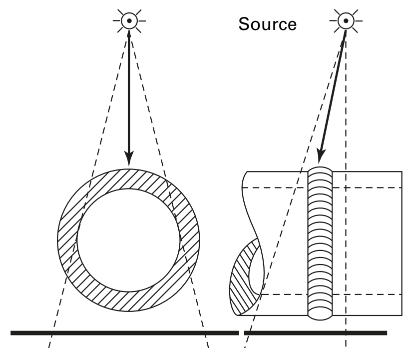
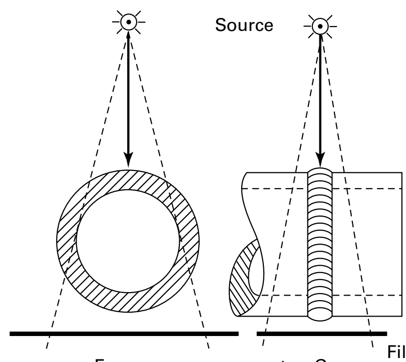
Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement: End View	Source-Weld-Film Arrangement: Side View	IQI: Selection	IQI: Placement	Location Marker Placement
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — A		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Either Side T-275.3 T-275.1(c)
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — B		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — C		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Source Side T-275.1 (a)(3)

Figure A-210-2
Double-Wall Radiographic Techniques

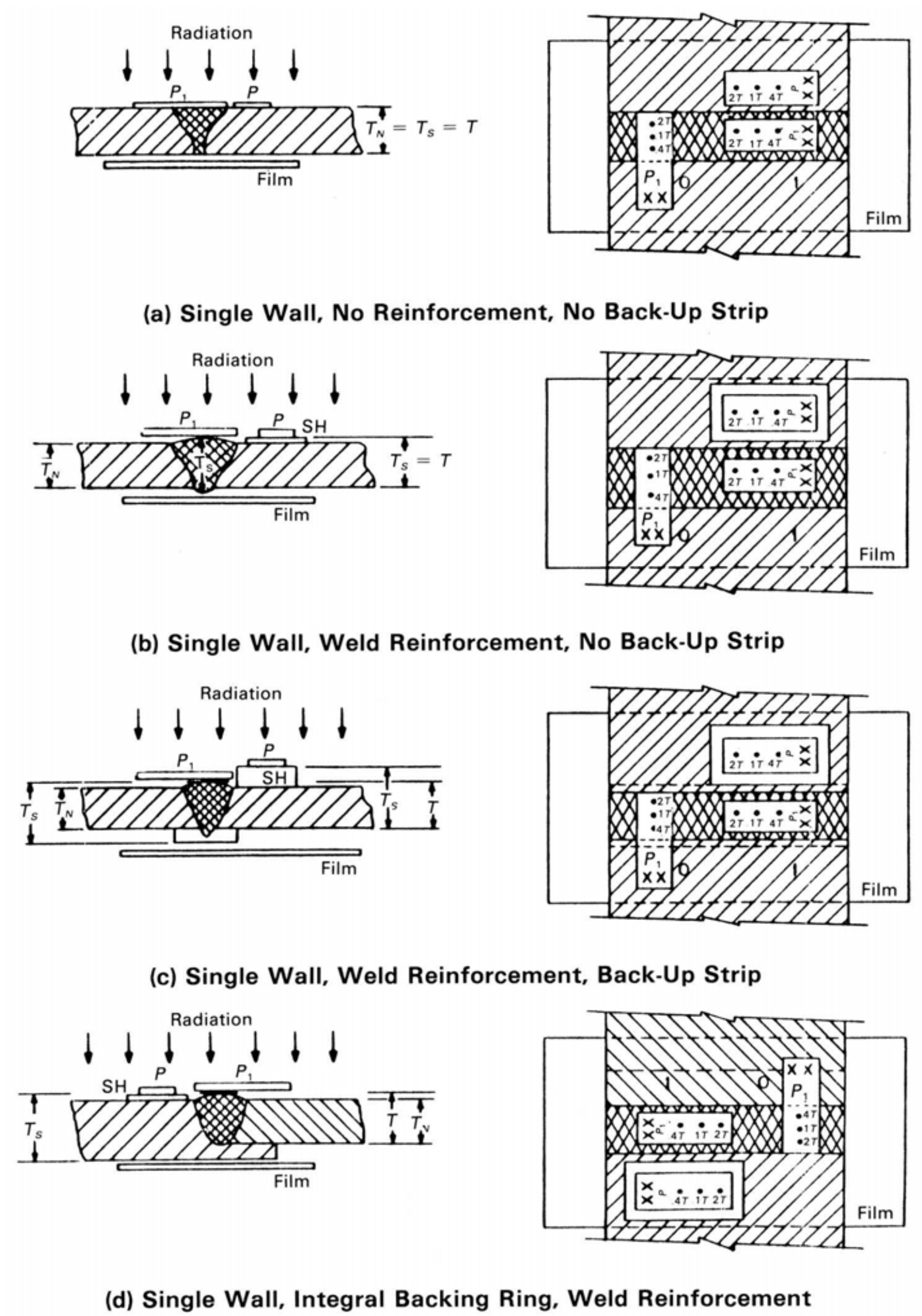
O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Double- Wall: T-271.2(a) at Least 3 Exposures 120 deg to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — D		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1(b)(1)
Any	Double- Wall: T-271.2(a) at least 3 Exposures 120 deg to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — E		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1(b)(1)
$3\frac{1}{2}$ in. (89 mm) or Less	Double-Wall T-271.2(b)(1) at Least 2 Exposures at 90 deg to Each Other for Complete Coverage	Double-Wall (Ellipse): Read Offset Source Side and Film Side Images	 Exposure arrangement — F		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2
$3\frac{1}{2}$ in. (89 mm) or Less	Double-Wall: T-271.2(b)(2) at Least 3 Exposures at 60 deg or 120 deg to Each Other for Complete Coverage	Double-Wall: Read Super-imposed Source Side and Film Side Images	 Exposure arrangement — G		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

NONMANDATORY APPENDIX C
HOLE-TYPE IQI PLACEMENT SKETCHES FOR WELDS

C-210 SCOPE

Figures C-210-1 through C-210-4 of this Appendix demonstrate typical IQI (hole type) placement for welds. These sketches are tutorial to demonstrate suggested locations of IQIs and are not intended to cover all configurations or applications of production radiography. Other IQI locations may be used provided they comply with the requirements of Article 2. Wire IQIs shall be placed in accordance with the requirements of Article 2.

Figure C-210-1
Side and Top Views of Hole-Type IQI Placements



(a) Single Wall, No Reinforcement, No Back-Up Strip

(b) Single Wall, Weld Reinforcement, No Back-Up Strip

(c) Single Wall, Weld Reinforcement, Back-Up Strip

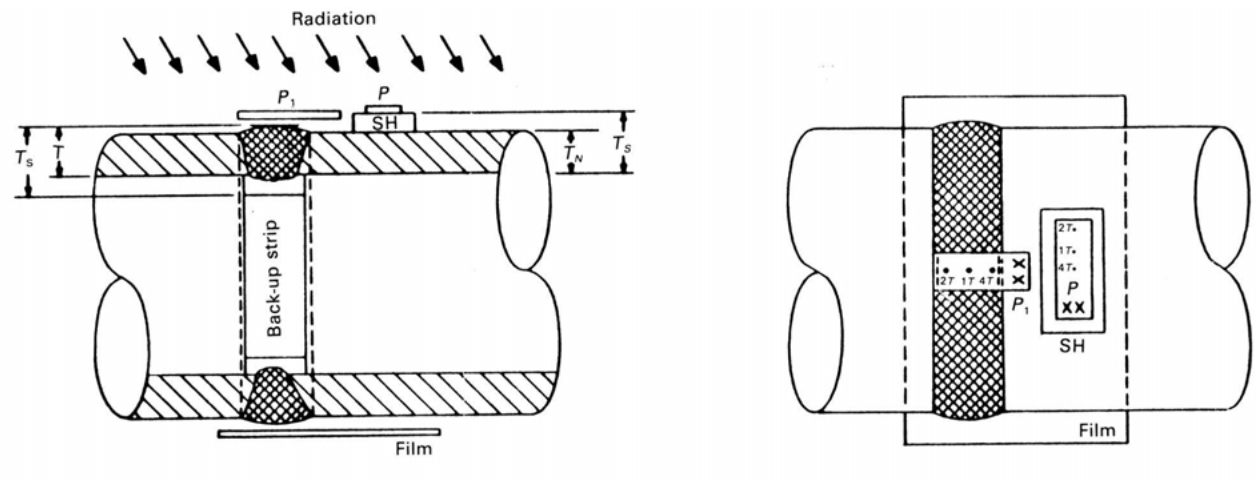
(d) Single Wall, Integral Backing Ring, Weld Reinforcement

Legend:

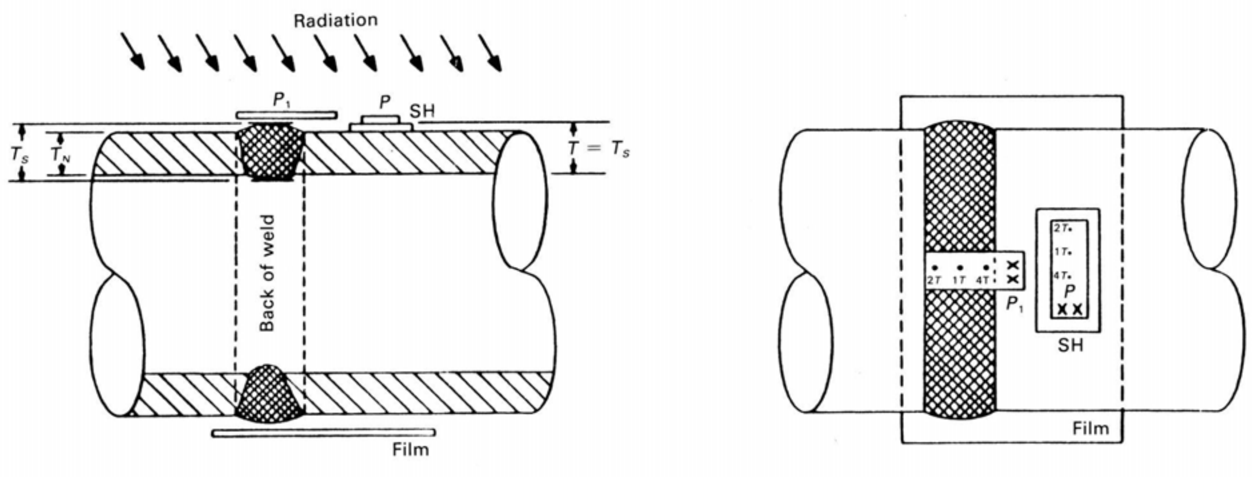
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

GENERAL NOTE: P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

Figure C-210-2
Side and Top Views of Hole-Type IQI Placements



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

Legend:

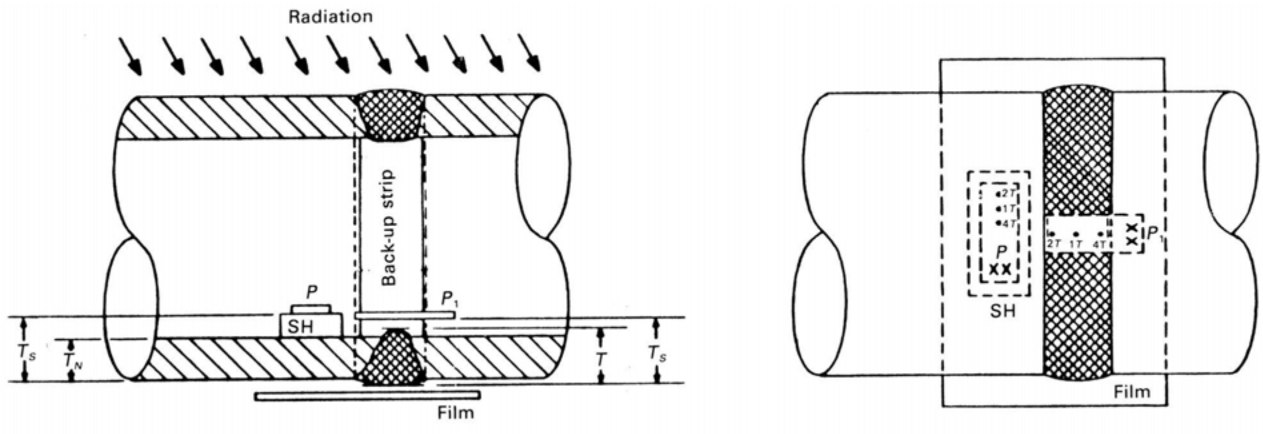
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

GENERAL NOTES:

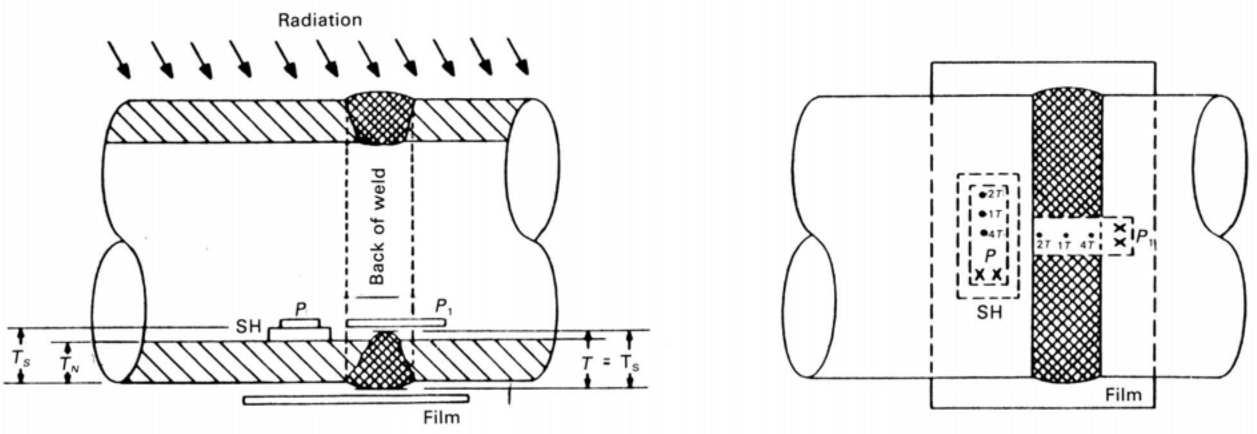
(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

(b) IQI is based on the single-wall thickness plus reinforcement.

Figure C-210-3
Side and Top Views of Hole-Type IQI Placements



(a) Double-Wall Technique, Single-Wall Viewing, Back-Up Strip



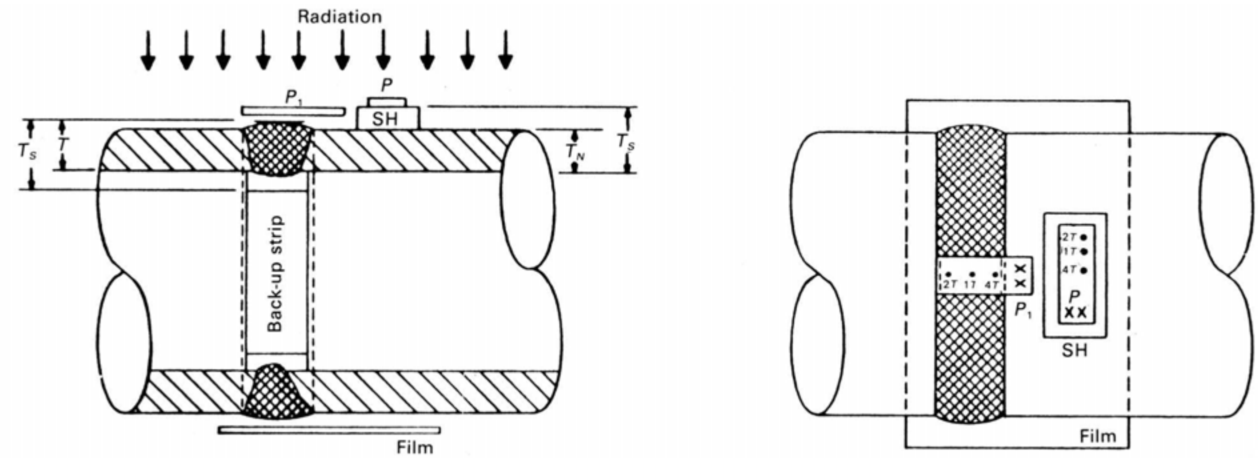
(b) Double-Wall Technique, Single-Wall Viewing, Wall Reinforcement, No Back-Up Strip

Legend:

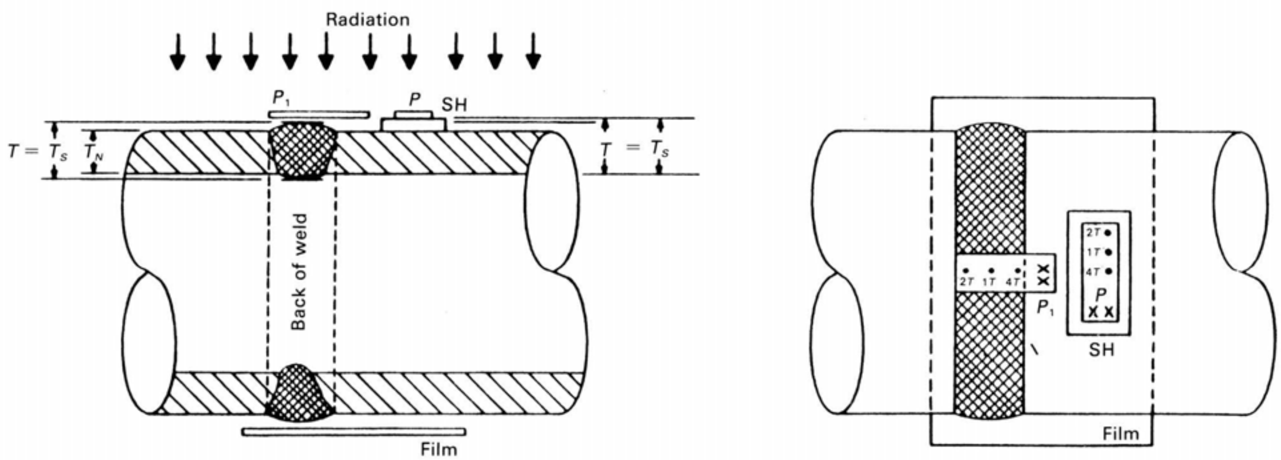
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

GENERAL NOTE: P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

Figure C-210-4
Side and Top Views of Hole-Type IQI Placements



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

Legend:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

GENERAL NOTES:

(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

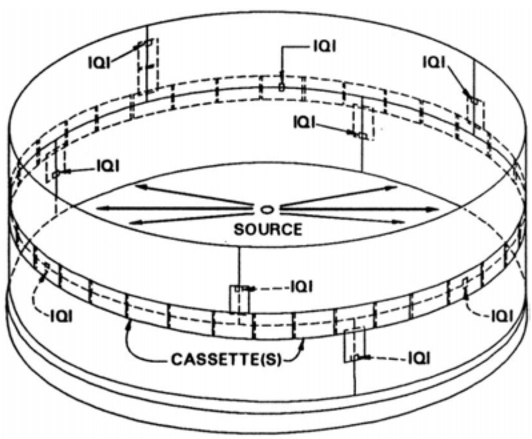
(b) IQI is based on the single-wall thickness plus reinforcement.

NONMANDATORY APPENDIX D
NUMBER OF IQIS (SPECIAL CASES)

D-210 SCOPE

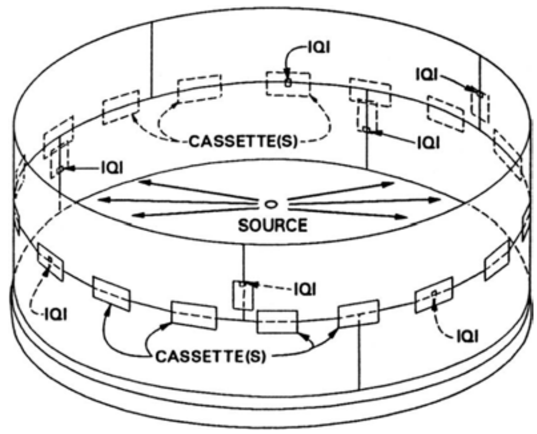
Figures D-210-1 through D-210-8 of this Appendix illustrate examples of the number and placement of IQIs that may be used in the special cases described in T-277.2(b). These figures are not intended to cover all configurations or applications of production radiography.

Figure D-210-1
Complete Circumference Cylindrical Component



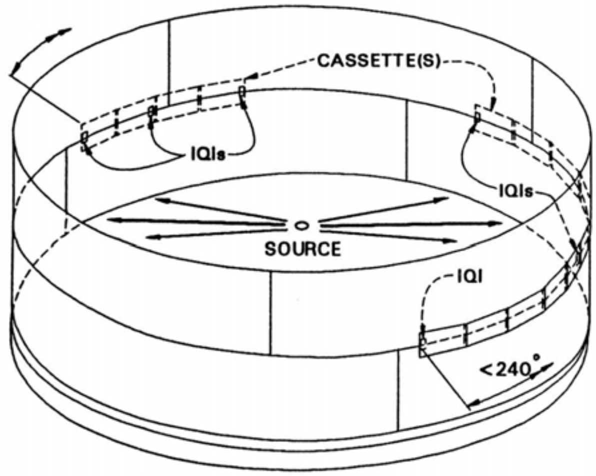
GENERAL NOTE: See T-277.2(b)(1)(-a) and T-277.2(b)(3).

Figure D-210-2
Section of Circumference 240 deg or More Cylindrical Component (Example is Alternate Intervals)



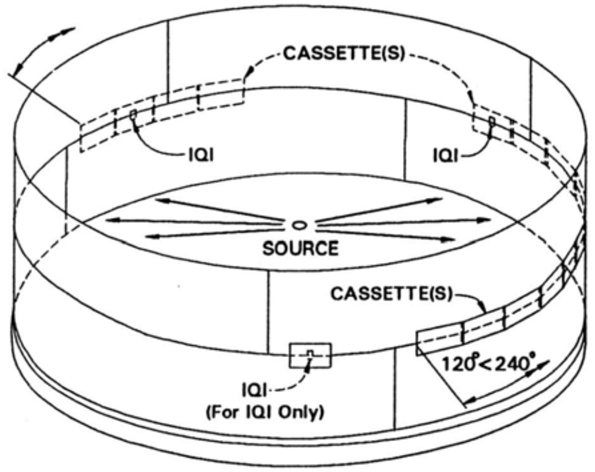
GENERAL NOTE: See T-277.2(b)(1)(-b) and T-277.2(b)(3).

Figure D-210-3
Section(s) of Circumference Less Than 240 deg Cylindrical Component



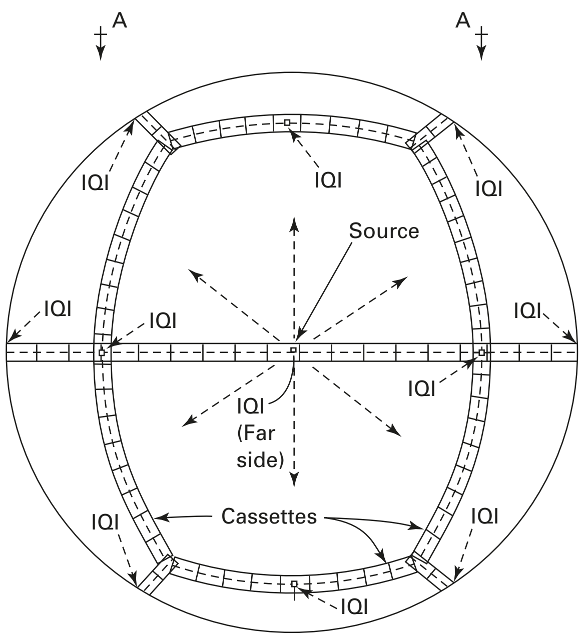
GENERAL NOTE: See T-277.2(b)(2)(-b).

Figure D-210-4
Section(s) of Circumference Equal to or More Than 120 deg and Less Than 240 deg Cylindrical Component Option



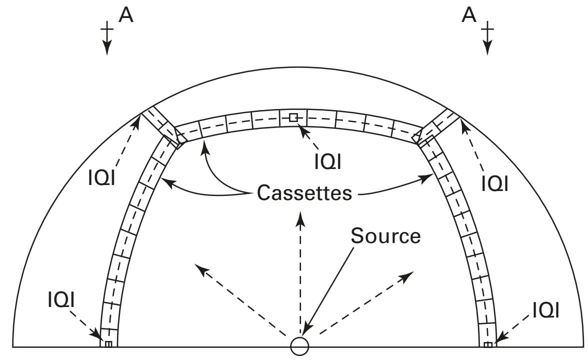
GENERAL NOTE: See T-277.2(b)(2)(-b).

Figure D-210-5
Complete Circumferential Welds Spherical Component



GENERAL NOTE: See T-277.2(b)(4)(-a) and T-277.2(b)(6).

Figure D-210-6
Welds in Segments of Spherical Component



GENERAL NOTE: See T-277.2(b)(5), T-277.2(b)(5)(-b), and T-277.2(b)(6).

Figure D-210-7
Plan View A-A

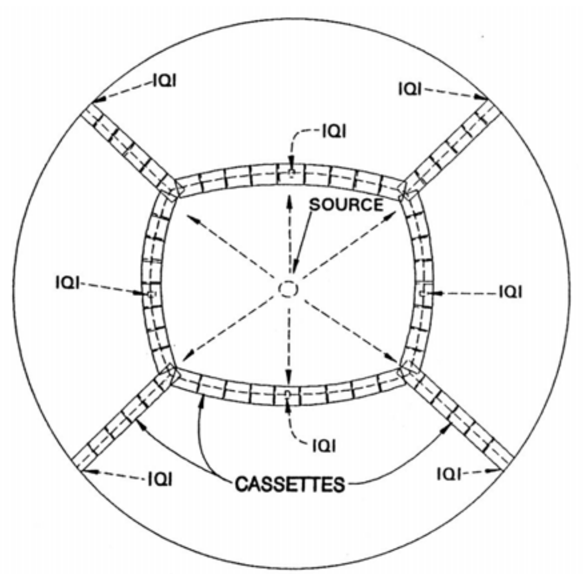
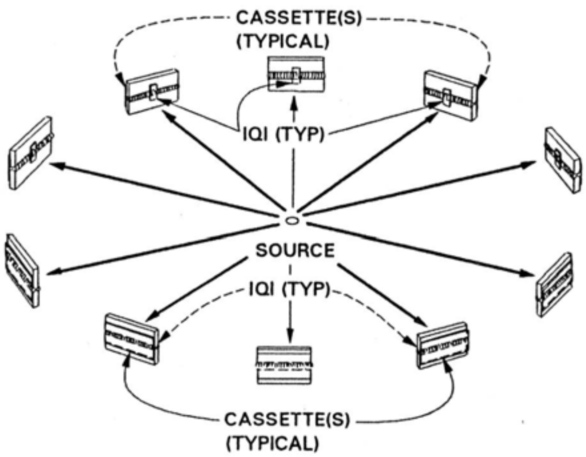


Figure D-210-8
Array of Objects in a Circle



GENERAL NOTES:
(a) Special cases IQI locations are typical in all figures.
(b) See T-277.2(b)(8).

ARTICLE 4
ULTRASONIC EXAMINATION METHODS FOR WELDS

T-410 SCOPE

This Article provides or references requirements for weld examinations, which are to be used in selecting and developing ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for the ultrasonic examination of welds and the dimensioning of indications for comparison with acceptance standards when required by the referencing Code Section; the referencing Code Section shall be consulted for specific requirements for the following:

(a) personnel qualification/certification requirements

(b) procedure requirements/demonstration, qualification, acceptance

(c) examination system characteristics

(d) retention and control of calibration blocks

(e) extent of examination and/or volume to be scanned

(f) acceptance standards

(g) retention of records

(h) report requirements

Definitions of terms used in this Article are contained in Article 1, Mandatory Appendix I, I-121.2, UT — Ultrasonics.

(19) T-420 GENERAL

The requirements of this Article shall be used together with Article 1, General Requirements. Refer to:

(a) special provisions for coarse grain materials and welds in T-451

(b) special provisions for computerized imaging techniques in T-452

(c) Mandatory Appendix III for Time of Flight Diffraction (TOFD) techniques

(d) Mandatory Appendix IV for phased array manual rastering techniques

(e) Mandatory Appendix V for phased array E-scan and S-scan linear scanning examination techniques

(f) Mandatory Appendix XI for full matrix capture (FMC) techniques

(19) T-421 WRITTEN PROCEDURE REQUIREMENTS

T-421.1 Requirements. Ultrasonic examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-421 or the Appendices applicable to the technique in use. The written procedure shall establish a single value, or range of values, for each requirement.

T-421.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-421 or the table in the Mandatory Appendix applicable to the technique in use, identified as an *essential variable* from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential variable* from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure or scan plan, as applicable.

T-430 EQUIPMENT

T-431 INSTRUMENT REQUIREMENTS

A pulse-echo-type of ultrasonic instrument shall be used. The instrument shall be capable of operation at frequencies over the range of at least 1 MHz to 5 MHz and shall be equipped with a stepped gain control in units of 2.0 dB or less. If the instrument has a damping control, it may be used if it does not reduce the sensitivity of the examination. The reject control shall be in the "off" position for all examinations, unless it can be demonstrated that it does not affect the linearity of the examination.

The instrument, when required because of the technique being used, shall have both send and receive jacks for operation of dual search units or a single search unit with send and receive transducers.

T-432 SEARCH UNITS

T-432.1 General. The nominal frequency shall be from 1 MHz to 5 MHz unless variables, such as production material grain structure, require the use of other frequencies to assure adequate penetration or better resolution. Search units with contoured contact wedges may be used to aid ultrasonic coupling.

T-432.2 Contact Wedges. As required by (a) and (b) below, examinations performed on a curved component having a diameter less than 14 in. (350 mm) (at the examination surface) shall be performed using a contoured wedge, to ensure sufficient ultrasonic coupling is

Table T-421
Requirements of an Ultrasonic Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Weld configurations to be examined, including thickness dimensions and base material product form (pipe, plate, etc.)	X	...
The surfaces from which the examination shall be performed	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...
Search unit type(s), frequency(ies), and element size(s)/shape(s)	X	...
Special search units, wedges, shoes, or saddles, when used	X	...
Ultrasonic instrument(s)	X	...
Calibration [calibration block(s) and technique(s)]	X	...
Directions and extent of scanning	X	...
Scanning (manual vs. automatic)	X	...
Method for discriminating geometric from flaw indications	X	...
Method for sizing indications	X	...
Computer enhanced data acquisition, when used	X	...
Scan overlap (decrease only)	X	...
Personnel performance requirements, when required	X	...
Personnel qualification requirements	...	X
Surface condition (examination surface, calibration block)	...	X
Couplant: brand name or type	...	X
Post-examination cleaning technique	...	X
Automatic alarm and/or recording equipment, when applicable	...	X
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X

achieved and to limit any potential rocking of the search unit as it is moved along the circumference of the component.

(a) Search units shall be contoured as required by the following equation:

$$D \leq \left[\frac{(A \times A)}{0.113\text{ in. }(2.87\text{ mm})} \right]$$

where

A = length of search unit footprint during circumferential scanning or the width when scanning in the axial direction, in. (mm)

D = the component diameter at inspection surface (I.D./O.D.), in. (mm)

The footprint is defined as the physical dimension of the search unit in the curved direction of the component.

(b) The search unit contoured dimension shall be selected from the tables in (1) and (2) below, and shall be determined using the same component dimension from which the examination is being performed (I.D. or O.D.).

(1) Maximum contour for examinations performed from O.D.

Actual Component Outside Diameter, in. (mm)	Allowable Increase in Contour Diameter Over Component O.D., in. (mm)
<4.0 (<100)	<1 (<25)
≥4.0 to 10 (≥100 to 250)	<2 (<50)
>10 (>250)	<4 (<100)

(2) Minimum contour for examinations performed from I.D.

Actual Component Inside Diameter, in. (mm)	Allowable Decrease in Contour Diameter Under Component I.D., in. (mm)
<4.0 (<100)	<1 (<25)
≥4.0 to 10 (≥100 to 250)	<2 (<50)
>10 (>250)	<4 (<100)

T-432.3 Weld Metal Overlay Cladding — Search Unit.[8] Dual element, straight beam search units using an angled pitch-catch technique shall be used. The included angle between the search unit's elements shall be such that the effective focal spot distance is centered in the area of interest.

T-433 COUPLANT

T-433.1 General. The couplant, including additives, shall not be detrimental to the material being examined.

T-433.2 Control of Contaminants.

(a) Couplants used on nickel base alloys shall not contain more than 250 ppm of sulfur.

(b) Couplants used on austenitic stainless steel or titanium shall not contain more than 250 ppm of halides (chlorides plus fluorides).

T-434 CALIBRATION BLOCKS

T-434.1 General.

T-434.1.1 Reflectors. Specified reflectors (i.e., side-drilled holes, flat bottom holes, notches, etc.) shall be used to establish primary reference responses of the equipment. An alternative reflector(s) may be used provided that the alternative reflector(s) produces a sensitivity equal to or greater than the specified reflector(s) (e.g., side-drilled holes in lieu of notches, flat bottom holes in lieu of side-drilled holes).

T-434.1.2 Material.

(a) Similar Metal Welds. The material from which the block is fabricated shall be of the same product form and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, 5A through 5C, and 15A through 15F materials are considered equivalent.

(b) Dissimilar Metal Welds. The material selection shall be based on the material on the side of the weld from which the examination will be conducted. If the examination will be conducted from both sides, calibration reflectors shall be provided in both materials.

(c) Transfer Correction. When the block material is not of the same product form or has not received the same heat treatment, it may be used provided it meets all other block requirements and a transfer correction for acoustical property differences is used. Transfer correction shall be determined by noting the difference between the signal response, using the same transducers and wedges to be used in the examination, received from either

(1) the corresponding reference reflector (same type and dimensions) in the basic calibration block and in the component to be examined, or

(2) two search units positioned in the same orientation on the basic calibration block and component to be examined.

The examination sensitivity shall be adjusted for the difference.

T-434.1.3 Quality. Prior to fabrication, the block material shall be completely examined with a straight beam search unit. Areas that contain an indication exceeding the remaining back-wall reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

T-434.1.4 Cladding.

(a) Block Selection. The material from which the block is fabricated shall be from one of the following:

(1) nozzle dropout from the component

(2) a component prolongation

(3) material of the same material specification, product form, and heat treatment condition as the material to which the search unit is applied during the examination

(b) Clad. Where the component material is clad and the cladding is a factor during examination, the block shall be clad to the component clad nominal thickness $\pm^1/_8$ in. (3 mm). Deposition of clad shall be by the same method (i.e., roll-bonded, manual weld deposited, automatic wire deposited, or automatic strip deposited) as used to clad the component to be examined. When the cladding method is not known or the method of cladding used on the component is impractical for block cladding, deposition of clad may be by the manual method.

When the parent materials on opposite sides of a weld are clad by either different P-, A-, or F-numbers or material designations or methods, the calibration block shall be clad with the same P-, A-, or F-numbers or material designations using the same method used on the side of the weld from which the examination will be conducted. When the examination is conducted from both sides of the weld, the calibration block shall provide for calibration for both materials and methods of cladding. For welds clad with a different material or method than the adjoining parent materials, and it is a factor during the examination, the calibration block shall be designed to be representative of this combination.

T-434.1.5 Heat Treatment. The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade. If the calibration block contains welds other than cladding, and the component weld at the time of the examination has been heat treated, the block shall receive the same heat treatment.

T-434.1.6 Surface Finish. The finish on the scanning surfaces of the block shall be representative of the scanning surface finishes on the component to be examined.

T-434.1.7 Block Curvature.

T-434.1.7.1 Materials With Diameters Greater Than 20 in. (500 mm). For examinations in materials where the examination surface diameter is greater than 20 in. (500 mm), a block of essentially the same curvature, or alternatively, a flat basic calibration block, may be used.

T-434.1.7.2 Materials With Diameters 20 in. (500 mm) and Less. For examinations in materials where the examination surface diameter is equal to or less than 20 in. (500 mm), a curved block shall be used. Except where otherwise stated in this Article, a single curved basic calibration block may be used for examinations in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (200 mm) diameter block may be used to calibrate for examinations on surfaces in the range of curvature from 7.2 in. to 12 in. (180 mm to 300 mm) in diameter. The curvature range from 0.94 in. to 20 in. (24 mm to 500 mm) in diameter requires six curved blocks as shown in Figure T-434.1.7.2 for any thickness range.

T-434.1.7.3 Alternative for Convex Surface. As an alternative to the requirements in T-434.1.7.1 when examining from the convex surface by the straight beam contact technique, Nonmandatory Appendix G may be used.

T-434.2 Non-Piping Calibration Blocks.

T-434.2.1 Basic Calibration Block. The basic calibration block configuration and reflectors shall be as shown in Figure T-434.2.1. The block size and reflector locations shall be adequate to perform calibrations for the beam angle(s) and distance range(s) to be used.

T-434.2.2 Block Thickness. The block thickness (T) shall be per Figure T-434.2.1.

T-434.2.3 Alternate Block. Alternatively, the block may be constructed as shown in Nonmandatory Appendix J, Figure J-431.

Figure T-434.1.7.2
Ratio Limits for Curved Surfaces

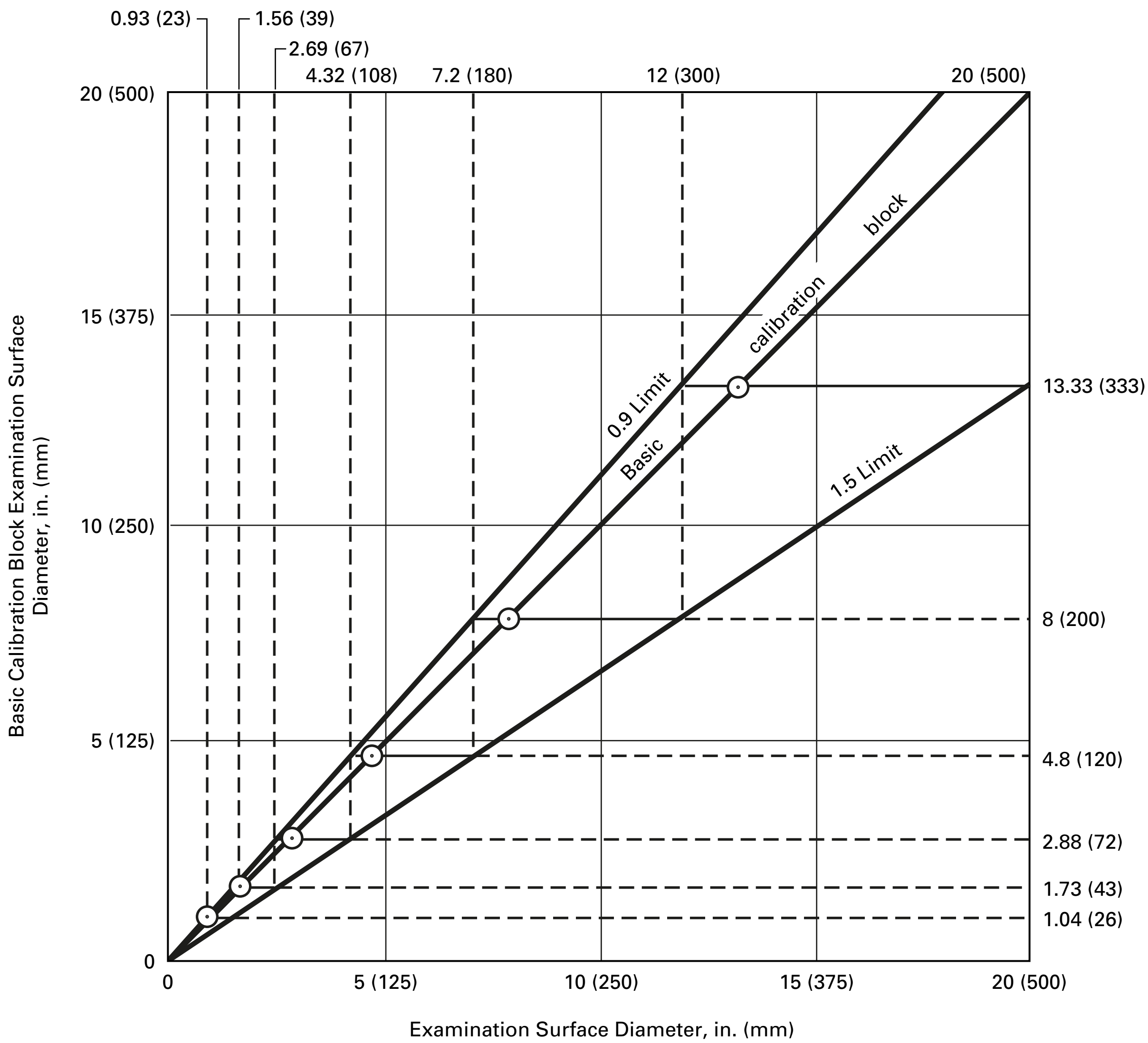
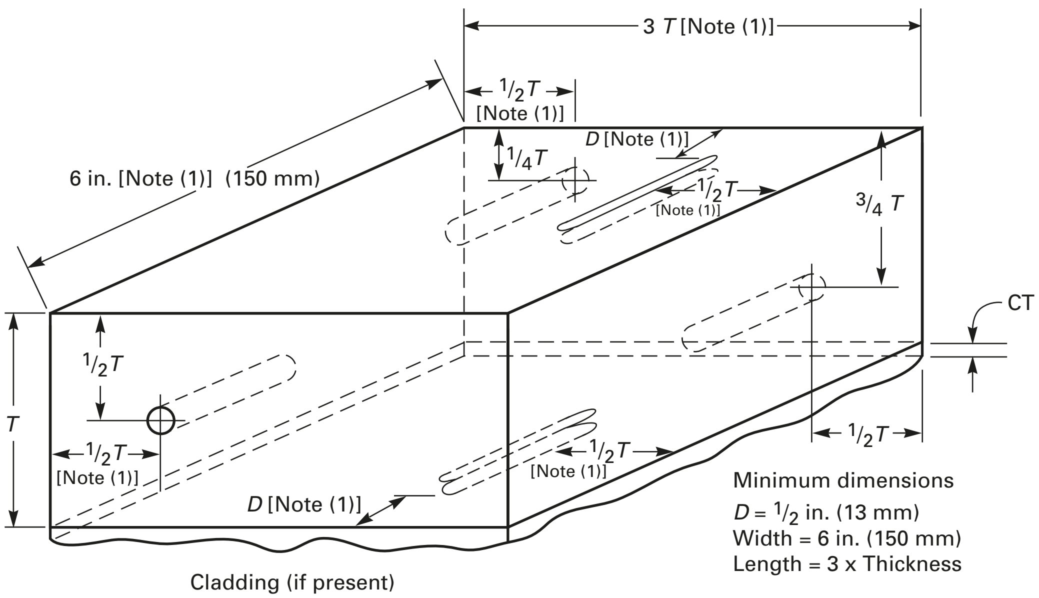


Figure T-434.2.1
Nonpiping Calibration Blocks



Notch Dimensions, in. (mm)
Notch depth = 1.6% T to 2.2% T
Notch width = $\frac{1}{4}$ (6) max.
Notch length = 1 (25) min.

Weld Thickness (t), in. (mm)	Calibration Block Thickness (T), in. (mm)	Hole Diameter, in. (mm)
Up to 1 (25)	$\frac{3}{4}$ (19) or t	$\frac{3}{32}$ (2.5)
Over 1 (25) through 2 (50)	$1\frac{1}{2}$ (38) or t	$\frac{1}{8}$ (3)
Over 2 (50) through 4 (100)	3 (75) or t	$\frac{3}{16}$ (5)
Over 4 (100)	t ±1 (25)	[Note (2)]

GENERAL NOTES:

(a) Holes shall be drilled and reamed 1.5 in. (38 mm) deep minimum, essentially parallel to the examination surface.

(b) For components equal to or less than 20 in. (500 mm) in diameter, calibration block diameter shall meet the requirements of T-434.1.7.2. Two sets of calibration reflectors (holes, notches) oriented 90 deg from each other shall be used. Alternatively, two curved calibration blocks may be used.

(c) The tolerance for hole diameter shall be ±$\frac{1}{32}$ in. (0.8 mm). The tolerance for hole location through the calibration block thickness (i.e., distance from the examination surface) shall be ±$\frac{1}{8}$ in. (3 mm).

(d) For blocks less than $\frac{3}{4}$ in. (19 mm) in thickness, only the $\frac{1}{2}T$ side-drilled hole and surface notches are required.

(e) All holes may be located on the same face (side) of the calibration block, provided care is exercised to locate all the reflectors (holes, notches) to prevent one reflector from affecting the indication from another reflector during calibration. Notches may also be in the same plane as the inline holes (see Nonmandatory Appendix J, Figure J-431). As in Figure J-431, a sufficient number of holes shall be provided for both angle and straight beam calibrations at the $\frac{1}{4}T$, $\frac{1}{2}T$, and $\frac{3}{4}T$ depths.

(f) When cladding is present, notch depth on the cladding side of the block shall be increased by the cladding thickness, CT (i.e., 1.6% T + CT minimum to 2.2% T + CT maximum).

(g) Maximum notch width is not critical. Notches may be made by EDM or with end mills up to $\frac{1}{4}$ in. (6.4 mm) in diameter.

(h) Weld thickness, t, is the nominal material thickness for welds without reinforcement or, for welds with reinforcement, the nominal material thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. When two or more base material thicknesses are involved, the calibration block thickness, T, shall be determined by the average thickness of the weld; alternatively, a calibration block based on the greater base material thickness may be used provided the reference reflector size is based upon the average weld thickness.

NOTES:

(1) Minimum dimension.

(2) For each increase in weld thickness of 2 in. (50 mm) or fraction thereof over 4 in. (100 mm), the hole diameter shall increase $\frac{1}{16}$ in. (1.5 mm).

T-434.3 Piping Calibration Blocks. The basic calibration block configuration and reflectors shall be as shown in Figure T-434.3-1 or the alternate provided in Figure T-434.3-2 where curvature and/or wall thickness permits. The basic calibration block curvature shall be in accordance with T-434.1.7. Thickness, *T*, shall be ±25% of the nominal thickness of the component to be examined. The block size and reflector locations shall be adequate to perform calibrations for the beam angle(s) and distance range(s) to be used.

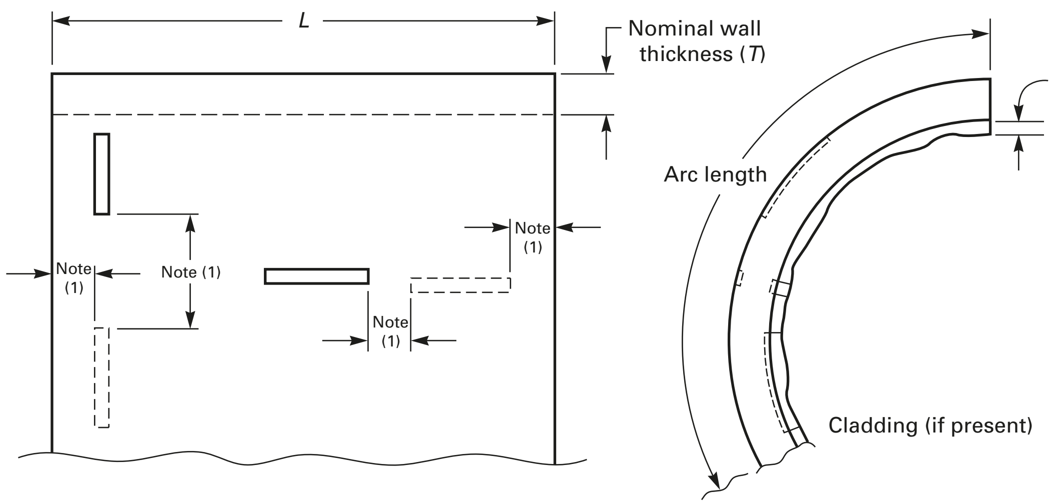
T-434.4 Weld Metal Overlay Cladding Calibration Blocks.[9]

T-434.4.1 Calibration Blocks for Technique One. The basic calibration block configuration and reflectors shall be as shown in Figure T-434.4.1. Either a side-drilled hole or flat bottom hole may be used. The thickness of the weld metal overlay cladding shall be at least as thick as that to be examined. The thickness of the base material shall be at least twice the thickness of the weld metal overlay cladding.

T-434.4.2 Alternate Calibration Blocks for Technique One. Alternately, calibration blocks as shown in Figure T-434.4.2.1 or Figure T-434.4.2.2 may be used. The thickness of the weld metal overlay cladding shall be at least as thick as that to be examined. The thickness of the base material shall be at least twice the thickness of the weld metal overlay cladding.

T-434.4.3 Calibration Block for Technique Two. The basic calibration block configuration and reflectors shall be as shown in Figure T-434.4.3. A flat bottom hole drilled to the weld/base metal interface shall be used. This hole may be drilled from the base material or weld metal overlay cladding side. The thickness of the weld metal overlay cladding shall be at least as thick as that to be examined. The thickness of the base metal shall be within 1 in. (25 mm) of the calibration block thickness when the examination is performed from the base material surface. The thickness of the base material on the

Figure T-434.3-1
Calibration Block for Piping

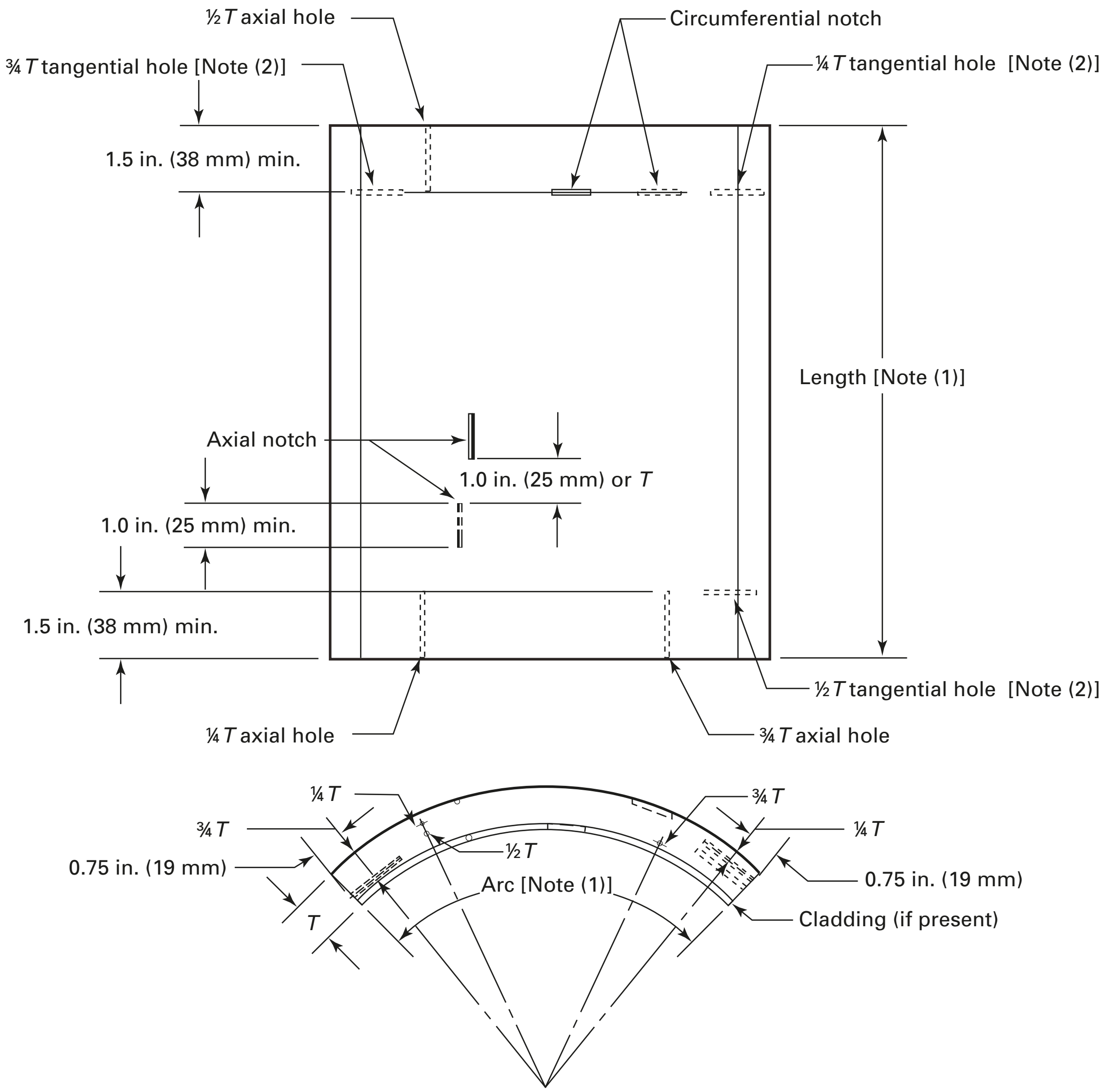


GENERAL NOTES:
(a) The minimum calibration block length, *L*, shall be 8 in. (200 mm) or 8*T*, whichever is greater.
(b) For O.D. 4 in. (100 mm) or less, the minimum arc length shall be 75% of the circumference. For O.D. greater than 4 in. (100 mm), the minimum arc length shall be 8 in. (200 mm) or 3*T*, whichever is greater.
(c) Notch depths shall be from 8% *T* minimum to 11% *T* maximum. When cladding is present, notch depths on the cladding side of the block shall be increased by the cladding thickness, CT (i.e., 8% *T* + CT minimum to 11% *T* + CT maximum). Notch widths shall be $^1/_4$ in. (6 mm) maximum. Notch lengths shall be 1 in. (25 mm) minimum.
(d) Maximum notch width is not critical. Notches may be made with EDM or with end mills up to $^1/_4$ in. (6 mm) in diameter.
(e) Notch lengths shall be sufficient to provide for calibration with a minimum 3 to 1 signal-to-noise ratio.
(f) Two blocks shall be used when a weld joining two different thicknesses of material is examined and a single block does not satisfy the requirements of T-434.3.
(g) When a flat block is used as permitted by T-434.1.7.1, the two axial notches may be omitted and the block width may be reduced to 4 in. (100 mm), provided the I.D. and O.D. notches are placed on opposite examination surfaces of the block. When cladding is not present, only one notch is required provided each examination surface is accessible during calibrations.

NOTE:
(1) Notches shall be located not closer than $^1/_2T$ or $^1/_2$ in. (13 mm), whichever is greater, to any block edge or to other notches.

(19)

Figure T-434.3-2
Alternate Calibration Block for Piping



GENERAL NOTES:

(a) For blocks less than $^3/_4$ in. (19 mm) in thickness, only the $^1/_2T$ side drilled hole is required..

(b) Inclusion of notches is optional. Notches as shown in Figure T-434.3-1 may be utilized in conjunction with this calibration block.

(c) Notch depths shall be from 8% T minimum to 11% T maximum. Notch widths shall be $^1/_4$ in. (6 mm) maximum. Notch lengths shall be 1 in. (25 mm) minimum.

(d) Notches may be made with EDM or with end mills up to $^1/_4$ in. (6 mm) in diameter.

(e) Notch lengths shall be sufficient to provide for calibration with a minimum 3 to 1 signal-to-noise ratio.

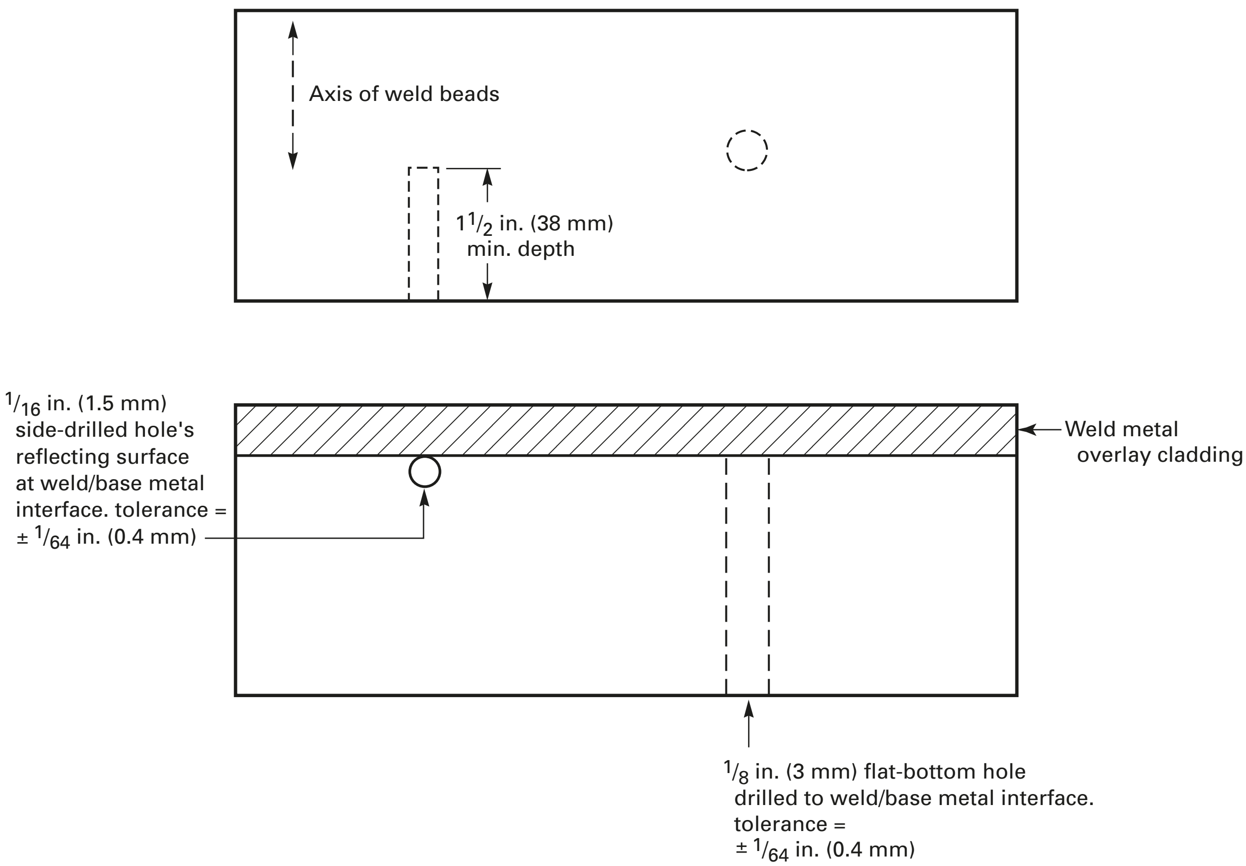
(f) Notches shall be located not closer than T or $1^1/_2$ in. (38 mm), whichever is greater, to any block edge or to other notches.

NOTES:

(1) Length and arc shall be adequate to provide required angle beam calibration.

(2) Side-drilled hole diameter, length, and tolerance shall be in accordance with T-434.2.1, as permitted by T-464.1.3. Tangential side-drilled holes at $^1/_4T$, $^1/_2T$, and $^3/_4T$ positions or locations are to have the depth confirmed at one-half of their length. The radius of the side-drilled hole shall be added to the measured depth to ensure the correct depth. Where thickness does not permit, the required depth of the side-drilled hole and the location of the tangential position shall be indicated on the block surface.

Figure T-434.4.1
Calibration Block for Technique One



calibration block shall be at least twice the thickness of the weld metal overlay cladding when the examination is performed from the weld metal overlay cladding surface.

T-434.5 Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal Calibration Blocks.

T-434.5.1 Calibration Block.

(a) Configuration. The calibration block configuration shall be as shown in Figure T-434.5.1. The block size and reflector locations shall be adequate to perform calibrations to cover the nozzle side weld fusion zone and/or the adjacent nozzle parent metal. If the internal surface of the nozzle is clad before the examination, the ID surface of the calibration block shall be clad.

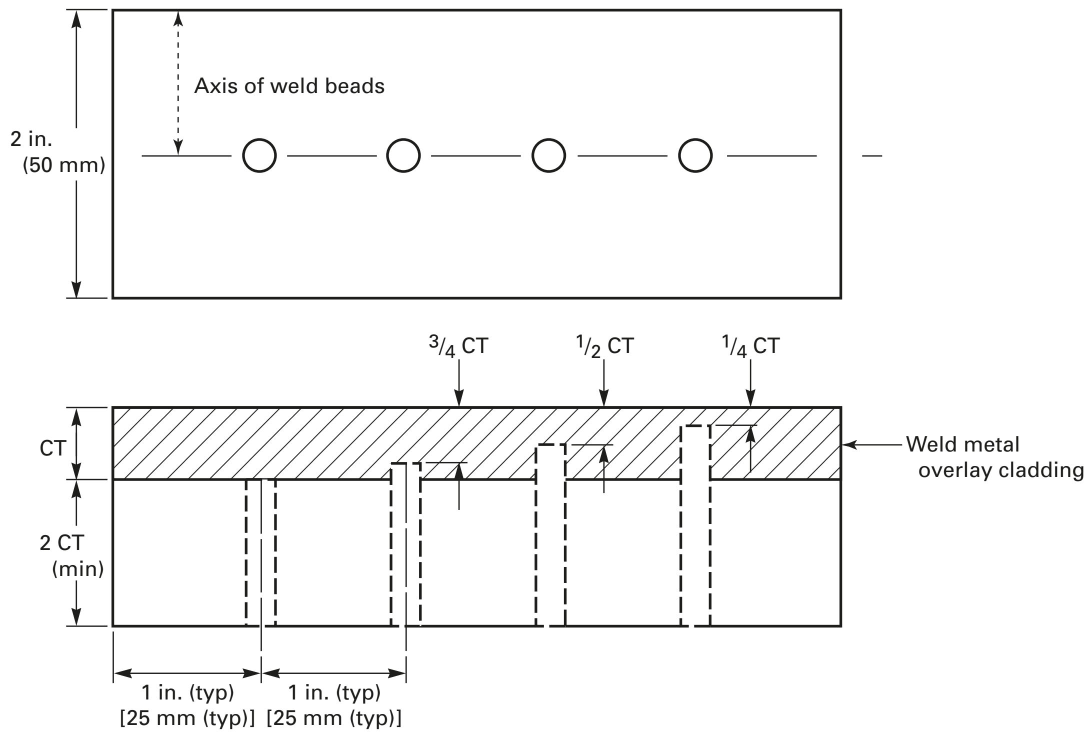
(b) Block Thickness. The calibration block shall be the maximum thickness of the nozzle wall adjacent to the nozzle weld plus $^3/_4$ in. (19 mm).

(c) Curvature. For examinations of nozzles with an inside diameter (I.D.) equal to or less than 20 in. (500 mm), the contact surface of the calibration block shall have the same curvature or be within the range of 0.9 to 1.5 times the diameter as detailed in Figure T-434.1.7.2.

(d) Calibration Reflectors. The calibration reflectors shall be side-drilled hole(s) that are in accordance with the requirements of Figure T-434.2.1 for the nozzle wall thickness.

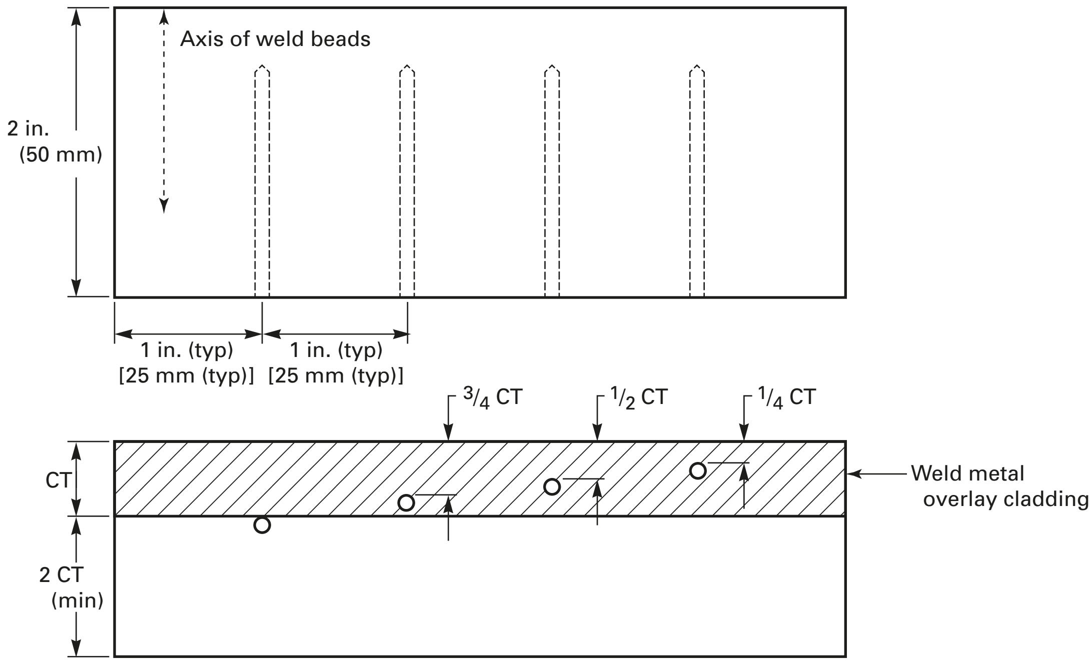
(e) Alternative Blocks. Alternative calibration blocks may be used for similar types of examinations provided the sound path distance(s) to the block's reflector(s) is (are) within $^1/_4$ in. (6 mm) of what is required and the side drilled hole(s) is (are) the same or a smaller diameter than what is required.

Figure T-434.4.2.1
Alternate Calibration Block for Technique One



GENERAL NOTE: All flat-bottom holes are $^1/_8$ in. (3 mm) diameter. Tolerances for hole diameter and depth with respect to the weld metal overlay cladding side of the block are $\pm^1/_{64}$ in. (0.4 mm).

Figure T-434.4.2.2
Alternate Calibration Block for Technique One



GENERAL NOTE: All side-drilled holes are $^{1}/_{16}$ in. (1.5 mm) diameter. Tolerances for hole diameter and depth with respect to the weld metal overlay cladding side of the block are $\pm^{1}/_{64}$ in. (0.4 mm). All holes drilled to a minimum depth of 1.5 in. (38 mm).

Figure T-434.4.3
Calibration Block for Technique Two

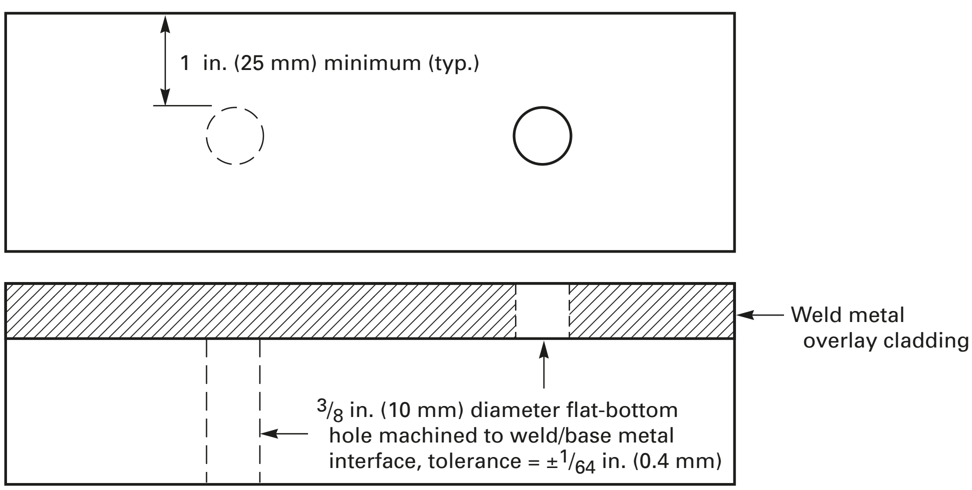
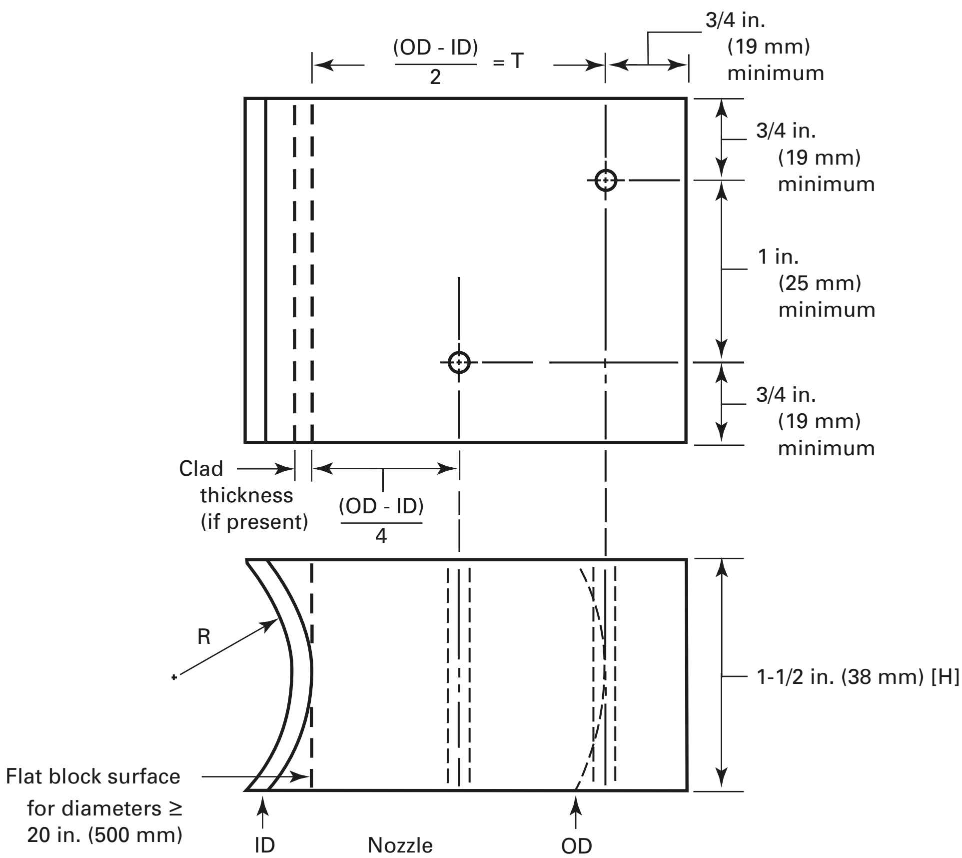


Figure T-434.5.1
Calibration Block for Straight Beam Examination of Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal



GENERAL NOTES:

(a) The thickness, T, of the calibration block (O.D. – I.D.)/2 shall be selected for the maximum nozzle wall thickness under the nozzle attachment weld.

(b) Side-drilled holes shall be drilled and reamed the full height, H, of the block.

(c) The diameter of the side-drilled holes shall be selected for the maximum nozzle wall thickness per (a) above and Figure T-434.2.1.

(d) For nozzle side examinations, when the wall thickness of the calibration block exceeds 2 in. (50 mm), additional side-drilled holes shall be placed in the block as required in the table below.

Calibration Block Wall Thickness, in. (mm)	Hole Location, $^5/_8T$	Hole Location, $^3/_4T$	Hole Location, $^7/_8T$
> 2 (50) through 3 (75)	...	X	...
> 3 (75)	X	X	X

T-440 MISCELLANEOUS REQUIREMENTS

T-441 IDENTIFICATION OF WELD EXAMINATION AREAS

(a) Weld Locations. Weld locations and their identification shall be recorded on a weld map or in an identification plan.

(b) Marking. If welds are to be permanently marked, low stress stamps and/or vibratooling may be used. Markings applied after final stress relief of the component shall not be any deeper than $^3/_{64}$ in. (1.2 mm).

(c) Reference System. Each weld shall be located and identified by a system of reference points. The system shall permit identification of each weld center line and designation of regular intervals along the length of the weld. A general system for layout of vessel welds is described in Article 4, Nonmandatory Appendix A; however, a different system may be utilized provided it meets the above requirements.

T-450 TECHNIQUES

The techniques described in this Article are intended for applications where either single or dual element search units are used to produce:

(a) normal incident longitudinal wave beams for what are generally termed ***straight beam*** examinations or

(b) angle beam longitudinal waves, where both refracted longitudinal and shear waves are present in the material under examination. When used for thickness measurement or clad examination, these examinations are generally considered to be straight beam examinations. When used for weld examinations, they are generally termed ***angle beam*** examinations or

(c) angle beam shear waves, where incident angles in wedges produce only refracted shear waves in the material under examination are generally termed ***angle beam*** examinations.

Contact or immersion techniques may be used. Base materials and/or welds with metallurgical structures producing variable attenuations may require that longitudinal angle beams are used instead of shear waves. Additionally, computerized imaging techniques may enhance the detectability and evaluation of indications.

Other techniques or technology which can be demonstrated to produce equivalent or better examination sensitivity and detectability using search units with more than two transducer elements may be used. The demonstration shall be in accordance with Article 1, T-150(a).

T-451 COARSE GRAIN MATERIALS

Ultrasonic examinations of high alloy steels and high nickel alloy weld deposits and dissimilar metal welds between carbon steels and high alloy steels and high nickel alloys are usually more difficult than ferritic weld examinations. Difficulties with ultrasonic examinations can be caused by an inherent coarse-grained and/or a directionally-oriented structure, which can cause marked variations in attenuation, reflection, and refraction at grain boundaries and velocity changes within the grains. It is necessary to modify and/or supplement the provisions of this Article in accordance with T-150(a) when examining such welds in these materials. Additional items, which are required, are weld mockups with reference reflectors in the weld deposit and single or dual element angle beam longitudinal wave transducers.

T-452 COMPUTERIZED IMAGING TECHNIQUES

The major attribute of Computerized Imaging Techniques (CITs) is their effectiveness when used to characterize and evaluate indications; however, CITs may also be used to perform the basic scanning functions required for flaw detection. Computer-processed data analysis and display techniques are used in conjunction with nonautomated scanner, semiautomatic scanner, or automatic scanner technique(s) to produce two and three-dimensional images of flaws, which provides an enhanced capability for examining critical components and structures. Computer processes may be used to quantitatively evaluate the type, size, shape, location, and orientation of flaws detected by ultrasonic examination or other NDE methods. Descriptions for some CITs that may be used are provided in Nonmandatory Appendix E.

T-453 SCANNING TECHNIQUES

Examination may be performed by one of the following techniques:

(a) manual scanning using no scanner equipment

(b) nonautomated scanning using nonautomated scanner(s)

(c) semiautomated scanning using semiautomated scanner(s)

(d) automated scanning using automated scanner(s)

T-460 CALIBRATION

T-461 INSTRUMENT LINEARITY CHECKS

The requirements of T-461.1 and T-461.2 shall be met at intervals not to exceed three months for analog type instruments and one year for digital type instruments, or prior to first use thereafter.

T-461.1 Screen Height Linearity. The ultrasonic instrument's screen height linearity shall be evaluated in accordance with Mandatory Appendix I.

T-461.2 Amplitude Control Linearity. The ultrasonic instrument's amplitude control linearity shall be evaluated in accordance with Mandatory Appendix II.

T-462 GENERAL CALIBRATION REQUIREMENTS

T-462.1 Ultrasonic System. Calibrations shall include the complete ultrasonic system and shall be performed prior to use of the system in the thickness range under examination.

T-462.2 Calibration Surface. Calibrations shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the component from which the examination will be performed.

T-462.3 Couplant. The same couplant to be used during the examination shall be used for calibration.

T-462.4 Contact Wedges. The same contact wedges to be used during the examination shall be used for calibration.

T-462.5 Instrument Controls. Any control which affects instrument linearity (e.g., filters, reject, or clipping) shall be in the same position for calibration, calibration checks, instrument linearity checks, and examination.

T-462.6 Temperature. For contact examination, the temperature differential between the calibration block and examination surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature for examination.

T-462.7 Distance–Amplitude Correction (DAC). No point on the DAC curve shall be less than 20% of full screen height (FSH). When any portion of the DAC curve will fall below 20% FSH, a split DAC shall be used. The first calibration reflector on the second DAC shall start at 80% ± 5% FSH. When reflector signal-to-noise ratio precludes effective indication evaluation and characterization, a split DAC should not be used. (Article 4, Nonmandatory Appendix Q provides an example.)

T-463 CALIBRATION FOR NONPIPING

T-463.1 System Calibration for Distance–Amplitude Techniques.

T-463.1.1 Calibration Block(s). Calibrations shall be performed utilizing the calibration block shown in Figure T-434.2.1.

In cases such as single sided access welds (see T-472.2), the calibration block detailed in Figure T-434.2.1 may not provide the necessary sound path distances to the reference reflectors to provide distance–amplitude correction (DAC) that will fully cover the area of interest for the straight beam technique. In these cases, a second calibration block is required whose thickness (T) and reference reflector locations are based on the sound path distance that provides for coverage of the area of interest.

T-463.1.2 Techniques. Nonmandatory Appendices B and C provide general techniques for both angle beam shear wave and straight beam calibrations. Other techniques may be used.

The angle beam shall be directed toward the calibration reflector that yields the maximum response in the area of interest. The gain control shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the other calibration reflectors at their beam paths to generate the distance–amplitude correction (DAC) curve. These calibrations shall establish both the distance range calibration and the distance–amplitude correction.

T-463.1.3 Angle Beam Calibration. As applicable, the calibration shall provide the following measurements (Nonmandatory Appendices B and M contain general techniques):

(a) distance range calibration;

(b) distance–amplitude;

(c) echo amplitude measurement from the surface notch in the basic calibration block.

When an electronic distance–amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

T-463.1.4 Alternative Angle Beam Calibration. When a vessel or other component is made with a thickness of $^1/_2$ in. (13 mm) or less and a diameter equal to or less than 20 in. (500 mm), the angle beam system calibrations for distance–amplitude techniques may be performed using the requirements of T-464.1.1 and T-464.1.2.

T-463.1.5 Straight Beam Calibration. The calibration shall provide the following measurements (Nonmandatory Appendix C gives a general technique):

(a) distance range calibration; and

(b) distance–amplitude correction in the area of interest.

When an electronic distance–amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

T-463.2 System Calibration for Nondistance–Amplitude Techniques. Calibration includes all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination. Calibration may be by use of basic calibration blocks with artificial or discontinuity reflectors. Methods are provided in Nonmandatory Appendices B and C. Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-464 CALIBRATION FOR PIPING

T-464.1 System Calibration for Distance–Amplitude Techniques.

T-464.1.1 Calibration Block(s). Calibrations shall be performed utilizing the calibration block shown in Figure T-434.3-1 or the alternate provided in Figure T-434.3-2.

T-464.1.2 Angle Beam Calibration With Notches (Figure T-434.3-1). The angle beam shall be directed toward the notch that yields the maximum response. The gain control shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the calibration reflectors at the distance increments necessary to generate a three-point distance–amplitude correction (DAC) curve. Separate calibrations shall be established for both the axial and circumferential notches. These calibrations shall establish both the distance range calibration and the distance–amplitude correction.

T-464.1.3 Calibration With Side-Drilled Holes (Figure T-434.3-2). The angle beam shall be directed toward the side-drilled hole that yields the maximum response. The gain control shall be set so that this response is 80% ±5% of full screen height. This shall be the primary reference level. The search unit shall then be manipulated, without changing the instrument settings, to obtain the maximum responses from the calibration reflectors at the distance increments necessary to generate up to a $3T$ distance–amplitude correction (DAC) curve, where T is the thickness of the calibration block. Next, position the search unit for the maximum response for the surface notch positions and mark the peaks on the screen for consideration when evaluating surface reflectors. Separate calibrations shall be established for both the axial and circumferential scans. These calibrations shall establish both the distance range calibration and the distance–amplitude correction.

T-464.1.4 Straight Beam Calibration. When required, straight beam calibrations shall be performed to the requirements of Nonmandatory Appendix C using the side-drilled hole alternate calibration reflectors of T-434.1.1. This calibration shall establish both the distance range calibration and the distance–amplitude correction.

T-464.2 System Calibration for Nondistance–Amplitude Techniques. Calibration includes all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination. Calibration may be by use of basic calibration blocks with artificial or discontinuity reflectors. Methods are provided in Nonmandatory Appendices B and C. Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-465 CALIBRATION FOR WELD METAL OVERLAY CLADDING

T-465.1 Calibration for Technique One. Calibrations shall be performed utilizing the calibration block shown in Figure T-434.4.1. The search unit shall be positioned for the maximum response from the calibration reflector. When a side-drilled hole is used for calibration, the plane separating the elements of the dual element search unit shall be positioned parallel to the axis of the hole. The gain control shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level.

T-465.2 Calibration for Technique Two. Calibrations shall be performed utilizing the calibration block shown in Figure T-434.4.3. The search unit shall be positioned for the maximum response of the first resolvable indication from the bottom of the calibration reflector. The gain shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level.

T-465.3 Alternate Calibration for Technique One. Calibrations shall be performed utilizing the calibration blocks shown in Figure T-434.4.2.1 or Figure T-434.4.2.2. The calibration shall be performed as follows:

(a) The search unit shall be positioned for maximum response from the reflector, which gives the highest amplitude.

(b) When the block shown in Figure T-434.4.2.2 is used, the plane separating the elements of the dual element search unit shall be positioned parallel to the axis of the holes.

(c) The gain shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level. Mark the peak of the indication on the screen.

(d) Without changing the instrument settings, position the search unit for maximum response from each of the other reflectors and mark their peaks on the screen.

(e) Connect the screen marks for each reflector to provide a DAC curve.

T-466 CALIBRATION FOR NOZZLE SIDE WELD FUSION ZONE AND/OR ADJACENT NOZZLE PARENT METAL

The number of calibration holes used depends upon the requirements for the examination. If only the nozzle side fusion zone is to be examined, then only a single side-drilled hole at the nozzle wall thickness needs to be used.

(a) Single Hole. The response from a single side drilled hole shall be set at 80% ± 5% of full screen height. This is the primary reference level.

(b) Multiple Holes. The straight beam shall be directed toward the calibration reflector that yields the maximum response. The gain control shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the other hole position(s) to generate a distance–amplitude correction (DAC) curve.

T-467 CALIBRATION CONFIRMATION

T-467.1 System Changes. When any part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that distance range points and sensitivity setting(s) satisfy the requirements of T-467.3.

T-467.2 Calibration Checks. A calibration check on at least one of the reflectors in the basic calibration block or a check using a simulator shall be performed at the completion of each examination or series of similar examinations, and when examination personnel (except for automated equipment) are changed. The distance range and sensitivity values recorded shall satisfy the requirements T-467.3.

NOTE: Interim calibration checks between the required initial calibration and the final calibration check may be performed. The decision to perform interim calibration checks should be based on ultrasonic instrument stability (analog vs. digital), the risk of having to conduct reexaminations, and the benefit of not performing interim calibration checks.

T-467.2.1 Simulator Checks. Any simulator checks that are used shall be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration reflectors or blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the basic calibration block, at the conclusion of each period of extended use, or every three months, whichever is less.

T-467.3 Confirmation Acceptance Values.

T-467.3.1 Distance Range Points. If any distance range point has moved on the sweep line by more than 10% of the distance reading or 5% of full sweep, whichever is greater, correct the distance range calibration and note the correction in the examination record. All recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-467.3.2 Sensitivity Settings. If any sensitivity setting has changed by more than 20% or 2 dB of its amplitude, correct the sensitivity calibration and note the correction in the examination record. If the sensitivity setting has decreased, all data sheets since the last valid calibration check shall be marked void and the area covered by the voided data shall be reexamined. If the sensitivity setting has increased, all recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-470 EXAMINATION

T-471 GENERAL EXAMINATION REQUIREMENTS

T-471.1 Examination Coverage. The volume to be scanned shall be examined by moving the search unit over the scanning surface so as to scan the entire examination volume for each required search unit.

(a) Each pass of the search unit shall overlap a minimum of 10% of the transducer (piezoelectric element) dimension parallel to the direction of scan indexing. As an alternative, if the sound beam dimension parallel to the direction of scan indexing is measured in accordance with Nonmandatory Appendix B, B-466, Beam Spread measurement rules, each pass of the search unit may provide overlap of the minimum beam dimension determined.

(b) Oscillation of the search unit is permitted if it can be demonstrated that overlapping coverage is provided.

T-471.2 Pulse Repetition Rate. The pulse repetition rate shall be small enough to assure that a signal from a reflector located at the maximum distance in the examination volume will arrive back at the search unit before the next pulse is placed on the transducer.

T-471.3 Rate of Search Unit Movement. The rate of search unit movement (scanning speed) shall not exceed 6 in./s (150 mm/s), unless:

(a) the ultrasonic instrument pulse repetition rate is sufficient to pulse the search unit at least six times within the time necessary to move one-half the transducer (piezoelectric element) dimension parallel to the direction of the scan at maximum scanning speed; or,

(b) a dynamic calibration is performed on multiple reflectors, which are within 2 dB of a static calibration and the pulse repetition rate meets the requirements of T-471.2.

T-471.4 Scanning Sensitivity Level.

T-471.4.1 Distance–Amplitude Techniques. The scanning sensitivity level shall be set a minimum[10] of 6 dB higher than the reference level gain setting or, when a semi-automatic or automatic technique is used, it may be set at the reference level.

T-471.4.2 Nondistance–Amplitude Techniques. The level of gain used for scanning shall be appropriate for the configuration being examined and shall be capable of detecting the calibration reflectors at the maximum scanning speed.

T-471.5 Surface Preparation. When the base material or weld surface interferes with the examination, the base material or weld shall be prepared as needed to permit the examination.

T-471.6 Recording of Ultrasonic Data. The ultrasonic data for the semi-automatic and automatic techniques shall be recorded in an unprocessed form with no thresholding. Gating of the data solely for the recording of the examination volume is permitted, provided a scan plan is utilized to determine the gate settings to be used.

T-472 WELD JOINT DISTANCE–AMPLITUDE TECHNIQUE

When the referencing Code Section specifies a distance–amplitude technique, weld joints shall be scanned with an angle beam search unit in both parallel and transverse directions (4 scans) to the weld axis. Before performing the angle beam examinations, a straight beam examination shall be performed on the volume of base material through which the angle beams will travel to locate any reflectors that can limit the ability of the angle beam to examine the weld volume. Nonmandatory Appendix I describes a method of examination using multiple angle beam search units.

T-472.1 Angle Beam Technique.

T-472.1.1 Beam Angle. The search unit and beam angle selected shall be 45 deg or an angle appropriate for the configuration being examined and shall be capable of detecting the calibration reflectors, over the required angle beam path.

T-472.1.2 Reflectors Parallel to the Weld Seam. The angle beam shall be directed at approximate right angles to the weld axis from both sides of the weld (i.e., from two directions) on the same surface when possible. The search unit shall be manipulated so that the ultrasonic energy passes through the required volume of weld and adjacent base material.

T-472.1.3 Reflectors Transverse to the Weld Seam.

(a) Scanning With Weld Reinforcement. If the weld cap is not machined or ground flat, the examination shall be performed from the base material on both sides of the weld cap. While scanning parallel to the weld axis, the angle beam shall be directed from 0 deg to 60 deg with respect to the weld axis in both axial directions, with the angle beam passing through the required examination volume.

(b) Scanning Without Weld Reinforcement. If the weld cap is machined or ground flat, the examination shall be performed on the weld. While scanning, the angle beam shall be directed essentially parallel to the weld axis in both axial directions. The search unit shall be manipulated so that the angle beam passes through the required examination volume.

T-472.2 Single-Sided Access Welds. Welds that cannot be fully examined from two directions per T-472.1.2 using the angle beam technique shall also be examined to the maximum extent possible with a straight beam technique applied from an adjacent base material surface. This may be applicable to vessel corner and tee joints, nozzle and manway neck to shell or head joints, pipe to fittings, or branch connections. The area(s) of single-sided access and, if applicable, the extent of the limit coverage shall be noted in the examination report.

T-472.3 Inaccessible Welds. Welds that cannot be examined from at least one side (edge) using the angle beam technique shall be noted in the examination report. For flange welds, the weld may be examined with a straight beam or low angle longitudinal waves from the flange face provided the examination volume can be covered.

T-473 WELD METAL OVERLAY CLADDING TECHNIQUES

The techniques described in these paragraphs shall be used when examinations of weld metal overlay cladding are required by the referencing Code Section. When examination for lack of bond and weld metal overlay cladding flaw indications is required, Technique One shall be used. When examination for lack of bond only is required, Technique Two may be used.

T-473.1 Technique One. The examination shall be performed from the weld metal overlay clad surface with the plane separating the elements of the dual element search unit positioned parallel to the axis of the weld bead. The search unit shall be moved perpendicular to the weld direction.

T-473.2 Technique Two. The examination may be performed from either the weld metal overlay clad or unclad surface and the search unit may be moved either perpendicular or parallel to the weld direction.

T-474 NONDISTANCE–AMPLITUDE TECHNIQUES

The number of angles and directions of the scans, for reflectors both parallel and transverse to the weld axis, shall demonstrate the ability to detect the minimum size rejectable discontinuities in the referencing Code Section acceptance standards. The detailed techniques shall be in conformance with the requirements of the referencing Code Section.

T-475 NOZZLE SIDE WELD FUSION ZONE AND/OR ADJACENT NOZZLE PARENT METAL

T-475.1 Search Unit Location. When the referencing Code Section specifies that an ultrasonic examination be performed to examine either the nozzle side weld fusion zone and/or the adjacent nozzle parent metal, a straight beam examination shall be conducted from the inside nozzle surface.

T-475.2 Examination. The general examination requirements of T-471 are applicable. The full circumference of the nozzle shall be scanned to cover the entire nozzle side fusion zone of the weld plus 1 in. (25 mm) beyond the weld toes. The search unit may be moved either circumferentially around or axially across the examination zone. The screen range shall cover as a minimum, 1.1 times the full thickness of the nozzle wall. Nozzles that cannot be fully examined (e.g., restricted access that prevents hand placement of the search unit) shall be noted in the examination report.

T-477 POST-EXAMINATION CLEANING

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical after evaluation and documentation using a process that does not adversely affect the part.

T-480 EVALUATION

T-481 GENERAL

It is recognized that not all ultrasonic reflectors indicate flaws, since certain metallurgical discontinuities and geometric conditions may produce indications that are not relevant. Included in this category are plate segregates in the heat-affected zone that become reflective after fabrication. Under straight beam examination, these may appear as spot or line indications. Under angle beam examination, indications that are determined to originate from surface conditions (such as weld root geometry) or variations in metallurgical structure in austenitic materials (such as the automatic-to-manual weld clad interface) may be classified as geometric indications. The identity, maximum amplitude, location, and extent of reflector causing a geometric indication shall be recorded. [For example: internal attachment, 200% DAC, 1 in. (25 mm) above weld center line, on the inside surface, from 90 deg to 95 deg] The following steps shall be taken to classify an indication as geometric:

(a) Interpret the area containing the reflector in accordance with the applicable examination procedure.

(b) Plot and verify the reflector coordinates. Prepare a cross-sectional sketch showing the reflector position and surface discontinuities such as root and counterbore.

(c) Review fabrication or weld preparation drawings. Other ultrasonic techniques or nondestructive examination methods may be helpful in determining a reflector's true position, size, and orientation.

T-482 EVALUATION LEVEL

T-482.1 Distance–Amplitude Techniques. All indications greater than 20% of the reference level shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-482.2 Nondistance–Amplitude Techniques. All indications longer than 40% of the rejectable flaw size shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-483 EVALUATION OF LAMINAR REFLECTORS

Reflectors evaluated as laminar reflectors in base material which interfere with the scanning of examination volumes shall require the angle beam examination technique to be modified such that the maximum feasible volume is examined, and shall be noted in the record of the examination (T-493).

T-484 ALTERNATIVE EVALUATIONS

Reflector dimensions exceeding the referencing Code Section requirements may be evaluated to any alternative standards provided by the referencing Code Section.

T-490 DOCUMENTATION

T-491 RECORDING INDICATIONS

T-491.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-491.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indication (i.e., crack, nonfusion, slag, etc.), location, and extent (i.e., length) shall be recorded. Nonmandatory Appendices D and K provide general recording examples for angle and straight beam search units. Other techniques may be used.

T-492 EXAMINATION RECORDS

For each ultrasonic examination, the requirements of Article 1, T-190(a) and the following information shall be recorded:

(a) ultrasonic instrument identification (including manufacturer's serial number);

(b) search unit(s) identification (including manufacturer's serial number, frequency, and size);

(c) beam angle(s) used;

(d) couplant used, brand name or type;

(e) search unit cable(s) used, type and length;

(f) special equipment when used (search units, wedges, shoes, automatic scanning equipment, recording equipment, etc.);

(g) computerized program identification and revision when used;

(h) calibration block identification;

(i) simulation block(s) and electronic simulator(s) identification when used;

(j) instrument reference level gain and, if used, damping and reject setting(s);

(k) calibration data [including reference reflector(s), indication amplitude(s), and distance reading(s)];

(l) data correlating simulation block(s) and electronic simulator(s), when used, with initial calibration;

(m) identification and location of weld or volume scanned;

(n) surface(s) from which examination was conducted, including surface condition;

(o) map or record of rejectable indications detected or areas cleared;

(p) areas of restricted access or inaccessible welds.

Items (a) through (l) may be included or attached in a separate calibration record provided the calibration record is included in the examination record.

T-493 REPORT

A report of the examinations shall be made. The report shall include those records indicated in T-491 and T-492. The report shall be filed and maintained in accordance with the referencing Code Section.

T-494 STORAGE MEDIA

Storage media for computerized scanning data and viewing software shall be capable of securely storing and retrieving data for the time period specified by the referencing Code Section.

MANDATORY APPENDIX I
SCREEN HEIGHT LINEARITY

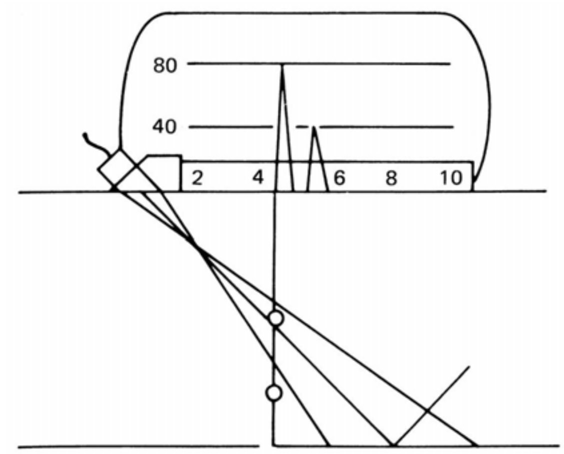
I-410 SCOPE

This Mandatory Appendix provides requirements for checking screen height linearity and is applicable to ultrasonic instruments with A-scan displays.

I-440 MISCELLANEOUS REQUIREMENTS

Position an angle beam search unit on a calibration block, as shown in Figure I-440 so that indications from both the $^1\!/_2T$ and $^3\!/_4T$ holes give a 2:1 ratio of amplitudes between the two indications. Adjust the sensitivity (gain) so that the larger indication is set at 80% of full screen height (FSH). Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading shall be 50% of the larger amplitude, within 5% of FSH. The settings and readings shall be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block that provides amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

Figure I-440
Linearity



MANDATORY APPENDIX II
AMPLITUDE CONTROL LINEARITY

II-410 SCOPE

This Mandatory Appendix provides requirements for checking amplitude control linearity and is applicable to ultrasonic instruments with A-scan displays.

II-440 MISCELLANEOUS REQUIREMENTS

Position an angle beam search unit on a basic calibration block, as shown in Figure I-440 so that the indication from the $^1/_2T$ side-drilled hole is peaked on the screen. Adjust the sensitivity (gain) as shown in the following table. The indication shall fall within the specified limits. Alternatively, any other convenient reflector from any calibration block may be used with angle or straight beam search units.

Indication Set at % of Full Screen	dB Control Change	Indication Limits % of Full Screen
80%	−6 dB	35% to 45%
80%	−12 dB	15% to 25%
40%	+6 dB	65% to 95%
20%	+12 dB	65% to 95%

The settings and readings shall be estimated to the nearest 1% of full screen.

MANDATORY APPENDIX III
TIME OF FLIGHT DIFFRACTION (TOFD) TECHNIQUE

III-410 SCOPE

This Mandatory Appendix describes the requirements to be used for a Time of Flight Diffraction (TOFD) examination of welds.

III-420 GENERAL

The requirements of Article 4 apply unless modified by this Appendix.

III-421 WRITTEN PROCEDURE REQUIREMENTS

III-421.1 Requirements. The requirements of Table T-421 and Table III-421 shall apply.

III-421.2 Procedure Qualification. The requirements of Table T-421 and Table III-421 shall apply.

III-430 EQUIPMENT

III-431 INSTRUMENT REQUIREMENTS

III-431.1 Instrument. The instrument shall provide a linear "A" scan presentation for both setting up scan parameters and for signal analysis. Instrument linearity shall be such that the accuracy of indicated amplitude or time is ±5% of the actual full-scale amplitude or time. The ultrasonic pulser may provide excitation voltage by tone burst, unipolar, or bipolar square wave. Pulse width shall be tunable to allow optimization of pulse amplitude and duration. The bandwidth of the ultrasonic receiver shall be at least equal to that of the nominal probe frequency and such that the −6dB bandwidth of the probe does not fall outside of the −6dB bandwidth of the receiver. Receiver gain control shall be available to adjust signal amplitude in increments of 1dB or less. Pre-amplifiers may be included in the system. Analog to digital conversion of waveforms shall have sampling rates at least four times that of the nominal frequency of the probe. When digital signal processing is to be carried out on the raw data, this shall be increased to eight times the nominal frequency of the probe.

Table III-421
Requirements of a TOFD Examination Procedure

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Instrument software	X	...
Directions and extent of scanning	X	...
Method for sizing flaw length	X	...
Method for sizing flaw height	X	...
Data sampling spacing (increase only)	X	...

III-431.2 Data Display and Recording. The data display shall allow for the viewing of the unrectified A-scan so as to position the start and length of a gate that determines the extent of the A-scan time-base that is recorded. Equipment shall permit storage of all gated A-scans to a magnetic or optical storage medium. Equipment shall provide a sectional view of the weld with a minimum of 64 gray scale levels. (Storage of just sectional images without the underlying A-scan RF waveforms is not acceptable.) Computer software for TOFD displays shall include algorithms to linearize cursors or the waveform time-base to permit depth and vertical extent estimations. In addition to storage of waveform data including amplitude and time-base details, the equipment shall also store positional information indicating the relative position of the waveform with respect to the adjacent waveform(s), i.e., encoded position.

III-432 SEARCH UNITS

III-432.1 General. Ultrasonic probes shall conform to the following minimum requirements:

(a) Two probes shall be used in a pitch-catch arrangement (TOFD pair).

(b) Each probe in the TOFD pair shall have the same nominal frequency.

(c) The TOFD pair shall have the same element dimensions.

(d) The pulse duration of the probe shall not exceed 2 cycles as measured to the 20dB level below the peak response.

(e) Probes may be focused or unfocused. Unfocused probes are recommended for detection and focused probes are recommended for improved resolution for sizing.

(f) Probes may be single element or phased array.

(g) The nominal frequency shall be from 2 MHz to 15 MHz unless variables, such as production material grain structure, require the use of other frequencies to assure adequate penetration or better resolution.

III-432.2 Cladding — Search Units for Technique One. The requirements of T-432.3 are not applicable to the TOFD technique.

III-434 CALIBRATION BLOCKS

III-434.1 General.

III-434.1.1 Reflectors. Side-drilled holes shall be used to confirm adequate sensitivity settings.

III-434.1.7 Block Curvature. Paragraph T-434.1.7 shall also apply to piping.

III-434.2 Calibration Blocks. Paragraph T-434.2 shall also apply to piping.

III-434.2.1 Basic Calibration Block. The basic calibration block configuration and reflectors shall be as shown in Figure III-434.2.1(a). A minimum of two holes per zone, if the weld is broken up into multiple zones, is required. See Figure III-434.2.1(b) for a two zone example. The block size and reflector location shall be adequate to confirm adequate sensitivity settings for the beam angles used.

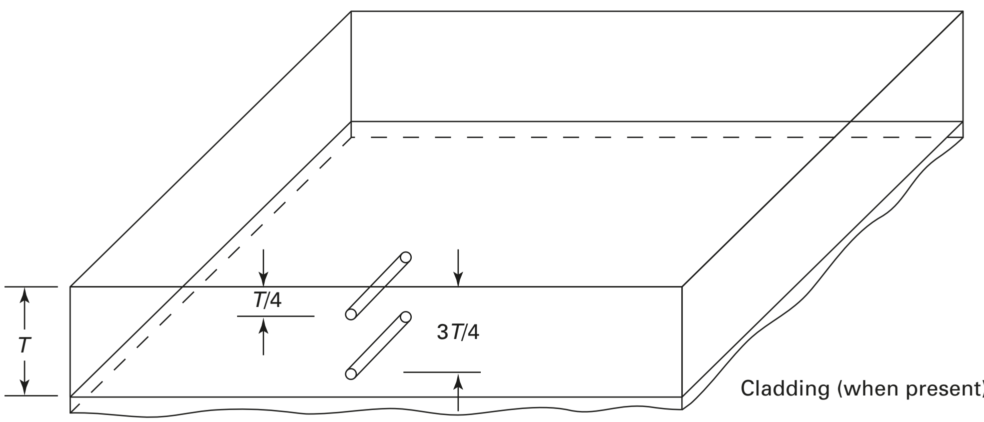
III-434.2.2 Block Thickness. The block thickness shall be at ±10% of the nominal thickness of the piece to be examined for thicknesses up to 4 in. (100 mm) or ±0.4 in. (10 mm) for thicknesses over 4 in. (100 mm). Alternatively, a thicker block may be utilized provided the reference reflector size is based on the thickness to be examined and an adequate number of holes exist to comply with T-434.2.1 requirements.

III-434.2.3 Alternate Block. The requirements of T-434.2.3 are not applicable to the TOFD technique.

III-434.3 Piping Calibration Block. The requirements of T-434.3 are not applicable to the TOFD technique.

III-434.4 Cladding Calibration Blocks. The requirements of T-434.4 are not applicable to the TOFD technique.

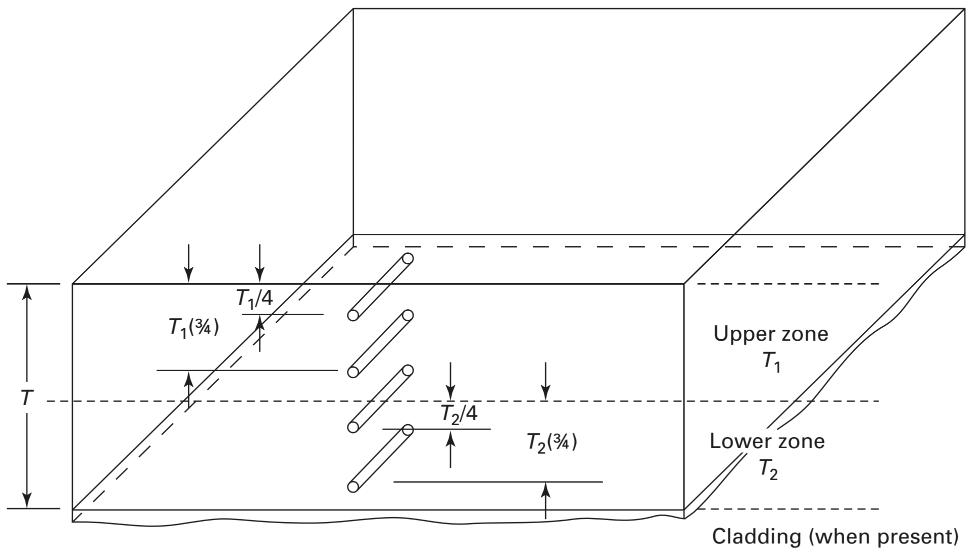
Figure III-434.2.1(a)
TOFD Reference Block



Weld Thickness, in. (mm)	Hole Diameter, in. (mm)
Up to 1 (25)	$^3/_{32}$ (2.5)
Over 1 (25) through 2 (50)	$^1/_8$ (3)
Over 2 (50) through 4 (100)	$^3/_{16}$ (5)
Over 4 (100)	$^1/_4$ (6)

GENERAL NOTES:
(a) Holes shall be drilled and reamed 2 in. (50 mm) deep minimum, essentially parallel to the examination surface and the scanning direction.
(b) *Hole Tolerance*. The tolerance on diameter shall be $\pm^1/_{32}$ in. (±0.8 mm). The tolerance on location through the block thickness shall be $\pm^1/_8$ in. (±3 mm).
(c) All holes shall be located on the same face (side) of the block and aligned at the approximate center of the face (side) unless the indication from one reflector affects the indication from another. In these cases, the holes may be located on opposite faces (sides) of the block.
(d) When the weld is broken up into multiple zones, each zone shall have a $T_z/4$ and $T_z(^3/_4)$ side drilled hole, where T_z is the zone thickness.
(e) For components ≤20 in. (500 mm) in diameter, calibration block diameter shall meet the requirements of T-434.1.7.2.

Figure III-434.2.1(b)
Two-Zone Reference Block Example



Legend:

T_1 = thickness of the upper zone

T_2 = thickness of the lower zone

III-435 MECHANICS

Mechanical holders shall be used to ensure that probe spacing is maintained at a fixed distance. The mechanical holders shall also ensure that alignment to the intended scan axis on the examination piece is maintained. Probe motion may be achieved using motorized or manual means and the mechanical holder for the probes shall be equipped with a positional encoder that is synchronized with the sampling of A-scans.

III-460 CALIBRATION

III-463 CALIBRATION

III-463.1 Calibration Block. Calibration shall be performed utilizing the calibration block shown in Figure III-434.2.1(a) or Figure III-434.2.1(b), as applicable.

III-463.2 Calibration. Set the TOFD probes on the surface to be utilized for calibration and set the gain control so that the lateral wave amplitude is from 40% to 90% of the full screen height (FSH) and the noise (grass) level is less than 5% to 10% FSH. This is the reference sensitivity setting. For multiple zone examinations when the lateral wave is not displayed, or barely discernible, set the gain control based solely on the noise (grass) level.

III-463.3 Confirmation of Sensitivity. Scan the calibration block's SDHs with them centered between the probes, at the reference sensitivity level set in III-463.2. The SDH responses from the required zone shall be a minimum of 6 dB above the grain noise and shall be apparent in the resulting digitized grayscale display.

III-463.4 Multiple Zone Examinations. When a weld is broken up into multiple zones, repeat III-463.2 and III-463.3 for each TOFD probe pair. In addition, the nearest SDH in the adjoining zone(s) shall be detected.

III-463.5 Width of Coverage Confirmation. Two additional scans per III-463.3 shall be made with the probes offset to either side of the applicable zone's weld edge ±$^1/_2$ in. (13 mm). If all the required holes are not detected, two additional offset scans are required with the probes offset by the distance(s) identified above. See Figure III-463.5 for an example.

III-463.6 Encoder. Encoders shall be calibrated per the manufacturer's recommendations and confirmed by moving a minimum distance of 20 in. (500 mm) and the displayed distance being ±1% of the actual distance moved.

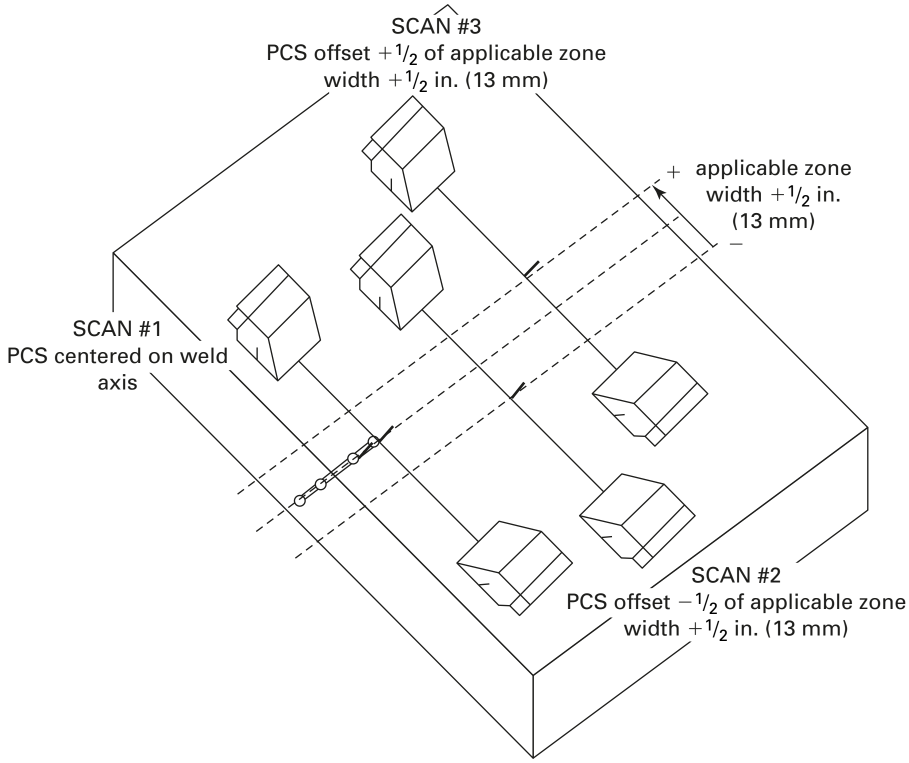
III-464 CALIBRATION FOR PIPING

The requirements of T-464 are not applicable to the TOFD technique.

III-465 CALIBRATION FOR CLADDING

The requirements of T-465 are not applicable to the TOFD technique.

Figure III-463.5
Offset Scans



III-467 ENCODER CONFIRMATION

A calibration check shall be performed at intervals not to exceed one month or prior to first use thereafter, made by moving the encoder along a minimum distance of 20 in. (500 mm) and the displayed distance being ±1% of the acutal distance moved.

III-470 EXAMINATION

III-471 GENERAL EXAMINATION REQUIREMENTS

III-471.1 Examination Coverage. The volume to be scanned shall be examined with the TOFD probe pair centered on and transverse to the weld axis and then moving the probe pair parallel to and along the weld axis. If offset scans are required due to the width of the weld, repeat the initial scan with the probes offset to one side of the weld axis and again with the offset to the opposite side of the first offset scan.

III-471.4 Overlap. The minimum overlap between adjacent scans shall be 1 in. (25 mm).

III-471.5 Multiple Zone Examination. When a weld is broken down into multiple zones, repeat III-471.1 for each weld zone.

III-471.6 Recording Data (Gated Region). The unrectified (RF waveform) A-scan signal shall be recorded. The A-scan gated region shall be set to start just prior to the lateral wave and, as a minimum, not end until all of the first back-wall signal with allowance for thickness and mismatch variations, is recorded. Useful data can be obtained from mode-converted signals; therefore, the interval from the first back-wall to the mode-converted back-wall signal shall also be included in the data collected when required by the referencing Code.

III-471.8 Reflectors Transverse to the Weld Seam. An angle beam examination shall be performed in accordance with T-472.1.3 for reflectors transverse to the weld axis unless the referencing Code Section specifies a TOFD examination. In these cases, position each TOFD probe pair essentially parallel to the weld axis and move the probe pair along and down the weld axis. If the weld reinforcement is not ground smooth, position the probes on the adjacent plate material as parallel to the weld axis as possible.

III-471.9 Supplemental I.D. and O.D. Near Surface Examination. Due to the presence of the lateral wave and back-wall indication signals, flaws occurring in these zones may not be detected. Therefore, the I.D. and O.D. near surfaces within the area of interest shall be examined per Article 4. This examination may be performed manually or mechanized; if mechanized, the data may be recorded in conjunction with the TOFD examination.

III-472 WELD JOINT DISTANCE–AMPLITUDE TECHNIQUE

The requirements of T-472 are not applicable to the TOFD technique.

III-473 CLADDING TECHNIQUE

The requirements of T-473 are not applicable to the TOFD technique.

III-475 DATA SAMPLING SPACING

A maximum sample spacing of 0.040 in. (1 mm) shall be used between A-scans collected for thicknesses under 2 in. (50 mm) and a sample spacing of up to 0.080 in. (2 mm) may be used for thicknesses greater than 2 in. (50 mm).

III-480 EVALUATION

III-485 MISSING DATA LINES

Missing lines in the display shall not exceed 5% of the scan lines to be collected, and no adjacent lines shall be missed.

III-486 FLAW SIZING AND INTERPRETATION

When height of flaw sizing is required, after the system is calibrated per III-463, a free run on the calibration block shall be performed and the depth of the back-wall reflection calculated by the system shall be within 0.04 in. (1 mm) of the actual thickness. For multiple zone examinations where the back wall is not displayed or barely discernible, a side-drilled hole or other known depth reference reflector in the calibration block may be used. See Nonmandatory Appendices L and N of this Article for additional information on flaw sizing and interpretation.

Final interpretation shall only be made after all display parameter adjustments (i.e., contrast, brightness, lateral and backwall removal and SAFT processing, etc.) have been completed.

III-490 DOCUMENTATION

III-492 EXAMINATION RECORD

For each examination, the required information in T-492 and the following information shall be recorded:

(a) probe center spacing (PCS)

(b) data sampling spacing

(c) flaw height, if specified

(d) the final display processing levels

III-493 REPORT

A report of the examination shall be made. The report shall include those records indicated in T-491, T-492, and III-492. The report shall be filed and maintained in accordance with the referencing Code Section.

MANDATORY APPENDIX IV PHASED ARRAY MANUAL RASTER EXAMINATION TECHNIQUES USING LINEAR ARRAYS

IV-410 SCOPE

This Mandatory Appendix describes the requirements to be used for phased array, manual raster scanning, ultrasonic techniques using linear arrays. The techniques covered by this Appendix are single (fixed angle), E-scan (fixed angle), and S-scan (sweeping multiple angle). In general, this Article is in conformance with SE-2700, Standard Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays. SE-2700 provides details to be considered in the procedures used.

IV-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

(19) IV-421 WRITTEN PROCEDURE REQUIREMENTS

IV-421.1 Requirements. The requirements of Table IV-421 shall apply.

IV-421.2 Procedure Qualification. The requirements of Table IV-421 shall apply.

(19) IV-422 SCAN PLAN

A scan plan shall be developed. The scan plan, in combination with the written procedure, shall address all requirements of Table IV-421.

IV-460 CALIBRATION

IV-461 INSTRUMENT LINEARITY CHECKS

IV-461.2 Amplitude Control Linearity. The ultrasonic instrument's amplitude control linearity shall be evaluated in accordance with Mandatory Appendix II for each pulser-receiver circuit.

IV-462 GENERAL CALIBRATION REQUIREMENTS

IV-462.7 Focal Law. The focal law to be used during the examination shall be used for calibration.

IV-462.8 Beam Calibration. All individual beams used in the examination shall be calibrated to provide measurement of distance and amplitude correction over the sound path employed in the examination. This shall include applicable compensation for wedge sound path variations and wedge attenuation effects.

IV-490 DOCUMENTATION

IV-492 EXAMINATION RECORD (19)

For each examination, the required information of T-492 and the following information shall be recorded:

(a) search unit type, element size and number, and pitch and gap dimensions

(b) focal law parameters, including, as applicable, angle, element numbers used, range of elements, element incremental change, angular range, and angle incremental change

(c) wedge angle

(d) instrument settings to include, as a minimum, excitation pulse type, duration and voltage settings, digitization rate (e.g., nominal rate as affected by compression and points quantity), rectification, pulse repetition rate, range start and stop, band pass filters, smoothing, focal type, and length

(e) scan plan variables

(19)

Table IV-421
Manual Linear Phased Array Raster Scanning Examination Procedure Requirements

Requirements (as Applicable)	Essential	Nonessential
Weld configurations examined, including joint design, thickness, and base material product form(s)	X	...
Surfaces from which the examination is performed	X	...
Surface condition (examination surface, calibration block)	X	...
Weld axis reference system and marking	...	X
Personnel qualification requirements	X	...
Personnel performance demonstration (if required)	X	...
Primary reference reflector and level	X	...
Calibration block(s) and technique(s)	X	...
Standardization method and reflectors (wedge delay, sensitivity, TCG)	X	...
Computerized data acquisition	...	X
Wedge cut/natural refracted angle	X	...
Wedge contouring and/or stabilizing features	X	...
Wedge height	X	...
Wedge type (solid wedge, water column, etc.)	X	...
Wedge material	X	...
Couplant: brand name or type	...	X
Instrument manufacturer and model, including all related operating modules	X	...
Instrument software and revision [Note (1)]	X	...
Special phased array probes, curved/shaped wedges, shoes, or saddles, when used	X	...
Search unit type (linear, dual linear, dual matrix, tandem, etc.)	X	...
Search unit detail (frequency, element size, number pitch, gap dimensions, element shape)	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...
Directions and extent of scanning	X	...
Scan increment (decrease in overlap amount)	X	...
Use of scan gain over primary reference level	X	...
Virtual aperture size (i.e., number of elements, effective height, and element width)	X	...
Focus length and plane (identify plane projection, depth, or sound path, etc.)	X	...
For E-scan:		
Range of element numbers used (i.e., 1–126, 10–50, etc.)	X	...
Element incremental change (i.e., 1, 2, etc.)	X	...
Rastering angle	X	...
Aperture start and stop numbers	X	...
For S-scan:		
Aperture element numbers (first and last)	X	...
Decrease in angular range used (i.e., 40 deg to 50 deg, 50 deg to 70 deg, etc.)	X	...
Maximum angle incremental change (i.e., $^1/_2$ deg, 1 deg, etc.)	X	...
For compound E-scan and S-scan: all E-scan and S-scan variables apply	X	...
Digitizing frequency	X	...
Net digitizing frequency (considers points quantity and other data compression)	X	...
Instrument dynamic range setting	X	...
Pulser voltage	X	...
Pulse type and width	X	...
Filters and smoothing	X	...
Pulse repetition frequency	X	...
Maximum range setting	X	...
Automatic alarm and/or recording equipment, when applicable	...	X
Method for discriminating geometric from flaw indications	X	...
Flaw characterization methodology	X	...
Method for measuring flaw length	X	...
Records, including minimum calibration data (e.g., instrument settings)	...	X
Post-exam cleaning	...	X

NOTE:
(1) Use of software revisions must be evaluated by the Level III for their impact on the functions as used. A limited extension of qualification may be determined to prove software functions. For example, addition of a software feature more capable than that qualified may be qualified by reanalysis of existing data. If a revision is implemented, personnel must receive training in use of the revised software.

MANDATORY APPENDIX V PHASED ARRAY E-SCAN AND S-SCAN LINEAR SCANNING EXAMINATION TECHNIQUES

V-410 SCOPE

This Mandatory Appendix describes the requirements to be used for phased array E-scan (fixed angle) and S-scan encoded linear scanning examinations using linear array search units.

V-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

(19) V-421 WRITTEN PROCEDURE REQUIREMENTS

V-421.1 Requirements. The requirements of Table V-421 shall apply.

V-421.2 Procedure Qualification. The requirements of Table V-421 shall apply.

(19) V-422 SCAN PLAN

A scan plan shall be developed. The scan plan, in combination with the written procedure, shall address all requirements of Table V-421.

V-460 CALIBRATION

V-461 INSTRUMENT LINEARITY CHECKS

V-461.2 Amplitude Control Linearity. The ultrasonic instrument's amplitude control linearity shall be evaluated in accordance with Mandatory Appendix II for each pulser-receiver circuit.

V-462 GENERAL CALIBRATION REQUIREMENTS

V-462.7 Focal Law. The focal law to be used during the examination shall be used for calibration.

V-462.8 Beam Calibration. All individual beams used in the examination shall be calibrated to provide measurement of distance and amplitude correction over the sound path employed in the examination.

V-467 ENCODER CALIBRATION

A calibration check shall be performed at intervals not to exceed one month or prior to first use thereafter, by moving the encoder a minimum distance of 20 in. (500 mm). The display distance shall be within 1% of the actual distance moved.

V-470 EXAMINATION

V-471 GENERAL EXAMINATION REQUIREMENTS

V-471.1 Examination Coverage. The required volume of the weld and base material to be examined shall be scanned using a linear scanning technique with an encoder. Each linear scan shall be parallel to the weld axis at a constant standoff distance with the beam oriented perpendicular to the weld axis.

(a) The search unit shall be maintained at a fixed distance from the weld axis by a fixed guide or mechanical means.

(b) The examination angle(s) for E-scan and range of angles for S-scan shall be appropriate for the joint to be examined.

(c) Scanning speed shall be such that data drop-out is less than 2 data lines/in. (25 mm) of the linear scan length and that there are no adjacent data line skips.

(d) For E-scan techniques, overlap between adjacent active apertures (i.e., aperture incremental change) shall be a minimum of 50% of the effective aperture height.

(e) For S-scan techniques, the angular sweep incremental change shall be a maximum of 1 deg or sufficient to assure 50% beam overlap.

(f) When multiple linear scans are required to cover the required volume of weld and base material, overlap between adjacent linear scans shall be a minimum of 10% of the effective aperture height for E-scans or beam width for S-scans.

V-471.6 Recording. A-scan data shall be recorded for the area of interest in an unprocessed form with no thresholding, at a minimum digitization rate of five times the examination frequency, and recording increments of a maximum of

(a) 0.04 in. (1 mm) for material < 3 in. (75 mm) thick

(b) 0.08 in. (2 mm) for material ≥ 3 in. (75 mm) thick

V-471.7 Reflectors Transverse to the Weld Seam. As an alternate to line scanning, a manual angle beam examination may be performed for reflectors transverse to the weld axis.

(19)

Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures

Requirements (as Applicable)	Workmanship		Fracture Mechanics	
	Essential	Nonessential	Essential	Nonessential
Weld configurations examined, including joint design thickness and base material product form	X	...	X	...
Surfaces from which examination is performed	X	...	X	...
Surface condition (examination surface, calibration block)	X	...	X	...
Weld axis reference system and marking	X	...	X	...
Personnel qualification requirements	X	...	X	...
Personnel performance demonstration (if required)	X	...	X	...
Primary reference reflector and level	X	...	X	...
Calibration [calibration block(s) and technique(s)]	X	...	X	...
Standardization method and reflectors (wedge delay, sensitivity, TCG)	X	...	X	...
Computerized data acquisition	X	...	X	...
Wedge cut/natural refracted angle	X	...	X	...
Wedge contouring and/or stabilizing features	X	...	X	...
Wedge height	X	...	X	...
Wedge roof angle, if applicable	X	...	X	...
Wedge type (solid wedge, water column, etc.)	X	...	X	...
Wedge material	X	...	X	...
Scanner type and fixturing	X	...	X	...
Search unit mechanical fixturing device (manufacturer and model), adhering and guiding mechanism	X	...	X	...
Search unit separation, if applicable	X	...	X	...
Couplant brand name or type	...	X	...	X
Instrument manufacturer and model, including all related operating modules	X	...	X	...
Instrument software and revision [Note (1)]	X	...	X	...
Use of separate data analysis software and revision [Note (1)]	X	...	X	...
Search unit type (linear, dual linear, dual matrix, tandem, etc.)	X	...	X	...
Search unit detail (frequency, element size, number pitch, gap dimensions, element shape)	X	...	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...	X	...
Direction and extent of scanning	X	...	X	...
Scanning technique (line vs. raster)	X	...	X	...
Scanning technique (automated vs. semiautomated)	X	...	X	...
Scanning (manual vs. encoded)	X	...	X	...
Scan increment (decrease in overlap)	X	...	X	...
Use of scan gain over primary reference level	X	...	X	...
Virtual aperture size (i.e., number of elements, effective height, and element width)	X	...	X	...
Focus length and plane (identify plane projection, depth, or sound path, etc.)	X	...	X	...
For E-scan				
Range of element numbers used (i.e., 1–126, 10–50, etc.)	X	...	X	...
Element incremental change (i.e., 1, 2, etc.)	X	...	X	...
Rastering angle	X	...	X	...
Aperture start and stop numbers	X	...	X	...
For S-scan:				
Aperture element numbers (first and last)	X	...	X	...
Decrease in angular range used (i.e., 40 deg to 50 deg, 50 deg to 70 deg, etc.)	X	...	X	...
Maximum angle incremental change (i.e., $^1/_2$ deg, 1 deg, etc.)	X	...	X	...
For compound E-scan and S-scan: all E-scan and S-scan variables apply	X	...	X	...
Digitizing frequency	X	...	X	...
Net digitizing frequency (considers digitization frequency together with points quantity or other data compression)	X	...	X	...
Instrument dynamic range setting	X	...	X	...
Pulser voltage	X	...	X	...
Pulse type and width	X	...	X	...
Filters and smoothing	X	...	X	...

Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures (Cont'd)

Requirements (as Applicable)	Workmanship		Fracture Mechanics	
	Essential	Nonessential	Essential	Nonessential
Pulse repetition frequency	X	...	X	...
Maximum range setting	X	...	X	...
Use of digital gain	X	...	X	...
Method for discriminating geometric from flaw indications	X	...	X	...
Flaw characterization methodology	X	...	NA	NA
Method for measuring flaw length	X	...	X	...
Method for measuring flaw height	NA	NA	X	...
Method for determining indication location relative to surface	NA	NA	X	...
Method for determining indication relative to other indications	NA	NA	X	...
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X	...	X
Post-exam cleaning	...	X	...	X

GENERAL NOTE: NA = not applicable.

NOTE:
(1) Use of later software revisions shall be evaluated by the Level III for their impact on the functions as used. A limited extension of qualification may be determined to prove software functions. For example, addition of a software feature more capable than that already qualified may be qualified by reanalysis of existing data. If a revision is implemented, personnel shall receive training in use of the revised software.

V-490 DOCUMENTATION

(19) V-492 EXAMINATION RECORD

For each examination, the required information of T-492 and the following information shall be recorded:

(a) search unit element size, number, and pitch and gap dimensions

(b) focal law parameters, including, as applicable, angle or angular range, element numbers used, angular or element incremental change, and start and stop element numbers or start element number

(c) wedge natural refracted angle

(d) instrument settings to include, as a minimum, excitation pulse type, duration and voltage settings, digitization rate (e.g., nominal rate as affected by compression and points quantity), rectification, pulse repetition rate, range start and stop, band pass filters, smoothing, focal type, and length

(e) scan plan variables

A-scan recorded data need only be retained until final flaw evaluation has been performed.

MANDATORY APPENDIX VII ULTRASONIC EXAMINATION REQUIREMENTS FOR WORKMANSHIP-BASED ACCEPTANCE CRITERIA

VII-410 SCOPE

This Mandatory Appendix provides requirements when an automated or semiautomated ultrasonic examination is performed for workmanship-based acceptance criteria.

VII-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

(19) **VII-421 WRITTEN PROCEDURE REQUIREMENTS**

VII-421.1 Requirements. Procedures shall be as detailed for the applicable ultrasonic technique.

VII-421.2 Procedure Qualification. The procedure and application scan plan(s) shall be qualified using the variables established for the applicable technique(s).

(19) **VII-423 PERSONNEL QUALIFICATIONS**

Only qualified UT personnel trained in the use of the equipment and who have demonstrated the ability to properly acquire examination data, shall conduct production scans. Personnel who approve setups, perform calibrations, and analyze and interpret the collected data shall be a Level II or Level III who have documented training in the use of the equipment and software used. The training and demonstration requirements shall be addressed in the employer's written practice.

VII-430 EQUIPMENT

VII-431 INSTRUMENT REQUIREMENTS

The ultrasonic examination shall be performed using a system employing automated or semiautomated scanning with computer based data acquisition and analysis abilities. The examination for transverse reflectors may be performed manually per T-472.1.3 unless the referencing Code Section specifies it also shall be by an automated or semiautomated scan.

(19) **Table VII-421**
Requirements of an Ultrasonic Examination Procedure for Workmanship-Based Acceptance Criteria

DELETED

VII-434 CALIBRATION BLOCKS

VII-434.1 Calibration and Scan Plan Verification. The following methods from either (a) or both (b) and (c) shall be used to verify the scan plan and examination calibration:

(a) Scanner Block. A block shall be fabricated meeting the requirements of T-434.1 and Figure T-434.2.1 except that its thickness, T, shall be within the lesser of $^1/_4$ in. (6 mm) or 25% of the material thickness to be examined and the number and position of the side-drilled holes shall be adequate to confirm the sensitivity setting of each probe, or probe pair in the case of a TOFD setup, as positioned per the scan plan in the scanner. The scanner block is in addition to the calibration block required per Article 4, unless the scanner block also has all the specified reference reflectors required per Figure T-434.2.1. For scanner block(s), VII-466.1 shall apply.

(b) Simulator Check. A simulator check shall be used prior to and at the end of each examination or series of exams. The simulator check may use any reference block (i.e., IIW, Rompus) or any block with a known reflector(s), provided that amplitude and time base signals can be identified and correlated to the original examination calibration. The time base position, amplitude, and known reflector shall be recorded on the calibration sheet(s). Accuracy of the simulator checks shall be verified at the conclusion of each period of extended use. For simulator checks VII-466.2.1 shall apply.

(c) Search Unit Position Verification. An adjustable scanner or search unit positioning system that is capable of measuring and securing the search unit shall be used for the purpose of maintaining and verifying a consistent probe position throughout the examination to the extent of ensuring that compliance with the scan plan has been achieved. VII-466.3 shall apply.

VII-440 MISCELLANEOUS REQUIREMENTS

VII-442 SCANNING DATA

The original scanning data, unprocessed, shall be saved electronically (e.g., magnetic, optical, flash memory, etc.).

VII-460 CALIBRATION

VII-466 CALIBRATION FOR NOZZLE SIDE WELD FUSION ZONE AND/OR ADJACENT NOZZLE PARENT METAL

VII-466.1 System Confirmation Scan. The scanner block shall be scanned and the reference reflector indications recorded to confirm system calibration prior to and at the completion of each examination or series of similar examinations, when examination personnel (except for automated equipment) are changed, and if the scan plan is required to be modified (i.e., VII-483) to satisfy the requirements of T-467.3.

VII-466.2 Calibration Checks. The requirements of T-467.2 are not applicable to this Appendix when the requirements of VII-434.1(a) are met.

VII-466.2.1 Simulator Checks. The requirements of T-467.2.1 are not applicable to this Appendix when the requirements of VII-434.1(a) are met.

VII-466.3 Search Unit Position. If the search unit position within the scanner has changed more than $^1/_{16}$ in. (1.5 mm), all data since the last valid search unit position check shall be marked void and the area covered by the voided data shall be reexamined. This requirement does not apply when the requirements of VII-434.1(a) are met.

VII-470 EXAMINATION

VII-471 GENERAL EXAMINATION REQUIREMENTS

VII-471.1 Examination Coverage. The volume to be scanned shall be examined per the scan plan.

VII-480 EVALUATION

VII-483 EVALUATION OF LAMINAR REFLECTORS

Reflectors evaluated as laminar reflectors in the base material which interfere with the scanning of the examination volume shall require the scan plan to be modified such that the maximum feasible volume is examined and shall be noted in the record of the examination (T-493).

VII-485 EVALUATION

Final flaw evaluation shall only be made after all display parameter adjustments (e.g., contrast, brightness, and, if applicable, lateral and backwall removal and SAFT processing, etc.) have been completed.

VII-486 SUPPLEMENTAL MANUAL TECHNIQUES

Flaws detected during the automated or semi-automated scan may be alternatively evaluated, if applicable, by supplemental manual techniques.

VII-487 EVALUATION BY MANUFACTURER

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed scan data to assure compliance with the requirements of Article 4, this Appendix, and the referencing Code Section. Acceptance shall be completed prior to presentation of the scan data and accompanying documentation to the Inspector.

VII-490 DOCUMENTATION

VII-492 EXAMINATION RECORD (19)

The required information of T-490 and the following information shall be recorded:

(a) scan plan (including qualified range of variables)

(b) scanner and adhering and guiding mechanism

(c) indication data [i.e., position in weld, length, and characterization (e.g., crack, lack of fusion, lack of penetration, or inclusion)]

(d) the final display processing levels

(e) supplemental manual technique(s) indication data, if applicable [same information as (c)]

(f) instrument settings to include, as a minimum, excitation pulse type, duration and voltage settings, digitization rate (e.g., nominal rate as affected by compression and points quantity), rectification, pulse repetition rate, range start and stop, band pass filters, smoothing, focal type, and length

(g) focal law parameters, including, as applicable, angle or angular range, focal depth and plane, element numbers used, angular or element incremental change, and start and stop element numbers or start element number

MANDATORY APPENDIX VIII ULTRASONIC EXAMINATION REQUIREMENTS FOR FRACTURE-MECHANICS-BASED ACCEPTANCE CRITERIA

(19) ## VIII-410 SCOPE

This Mandatory Appendix provides requirements when an automated or semiautomated ultrasonic examination is performed for fracture-mechanics-based acceptance criteria. When fracture-mechanics-based acceptance criteria are used with the full matrix capture (FMC) ultrasonic technique, Mandatory Appendix XI shall apply.

VIII-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

(19) ## VIII-421 WRITTEN PROCEDURE REQUIREMENTS

VIII-421.1 Requirements. Procedures shall be as detailed for the applicable ultrasonic technique.

VIII-421.2 Procedure Qualification. The procedure and applicable scan plan(s) shall be qualified using the variables established for the applicable technique(s).

(19) ## VIII-423 PERSONNEL QUALIFICATIONS

Only qualified UT personnel trained in the use of the equipment and who have participated in the technique qualification and/or demonstration or who have been trained and examined in the technique requirements, shall conduct production scans. Participation is defined as having collected data using the setup being qualified without assistance. Personnel who approve setups, perform calibrations, and analyze and interpret the collected data shall be a Level II or Level III who have documented training in the use of the equipment and software used. The training and demonstration requirements shall be addressed in the employer's written practice.

(19) **Table VIII-421 Requirements of an Ultrasonic Examination Procedure for Fracture-Mechanics-Based Acceptance Criteria**

DELETED

VIII-430 EQUIPMENT

VIII-431 INSTRUMENT REQUIREMENTS

The ultrasonic examination shall be performed using a system employing automated or semiautomated scanning with computer based data acquisition and analysis abilities. The examination for transverse reflectors may be performed manually per T-472.1.3 unless the referencing Code Section specifies it also shall be by an automated or semiautomated scan.

VIII-432 SEARCH UNITS

VIII-432.1 General. The nominal frequency shall be the same as used in the qualification. (19)

VIII-434 CALIBRATION BLOCKS

VIII-434.1 Calibration and Scan Plan Verification. The following methods from either (a) or both (b) and (c) shall be used to verify the scan plan and examination calibration.

(a) Scanner Block. A block shall be fabricated meeting the requirements of T-434.1 and Figure T-434.2.1 except that its thickness, T, shall be within the lesser of $^1/_4$ in. (6 mm) or 25% of the material thickness to be examined and the number and position of the side-drilled holes shall be adequate to confirm the sensitivity setting of each probe, or probe pair in the case of a TOFD setup, as positioned per the scan plan in the scanner. The scanner block is in addition to the calibration block required per Article 4, unless the scanner block also has all the specified reference reflectors required per Figure T-434.2.1. For scanner block(s), VIII-467.1 shall apply.

(b) Simulator Check. A simulator check shall be used prior to and at the end of each examination or series of exams. The simulator check may use any reference block (i.e., IIW, Rompus) or any block with a known reflector(s), provided that amplitude and time base signals can be identified and correlated to the original examination calibration. The time base position, amplitude, and known reflector shall be recorded on the calibration sheet(s). Accuracy of the simulator checks shall be verified at the conclusion of each period of extended use. For simulator checks T-467.2.1 shall apply.

(c) Search Unit Position Verification. An adjustable scanner or search unit positioning system that is capable of measuring and securing the search unit shall be used

for the purpose of maintaining and verifying a consistent probe position throughout the examination to the extent of ensuring that compliance with the scan plan has been achieved. VIII-467.3 shall apply.

VIII-440 MISCELLANEOUS REQUIREMENTS

VIII-442 SCANNING DATA

The original scanning data, unprocessed, shall be saved electronically (e.g., magnetic, optical, flash memory, etc.).

VIII-460 CALIBRATION

VIII-467 CALIBRATION FOR NOZZLE SIDE WELD FUSION ZONE AND/OR ADJACENT NOZZLE PARENT METAL

VIII-467.1 System Confirmation Scan. The scanner block shall be scanned and the reference reflector indications recorded to confirm that prior to and at the completion of each examination or series of similar examinations, when examination personnel (except for automated equipment) are changed, and if the scan plan is required to be modified (i.e., VIII-483) to satisfy the requirements of T-467.3.

VIII-467.2 Calibration Checks. The requirements of T-467.2 are not applicable to this Appendix when the requirements of VIII-434.1(a) are met.

VIII-467.2.1 Simulator Checks. The requirements of T-467.2.1 are not applicable to this Appendix when the requirements of VIII-434.1(a) are met.

VIII-467.3 Search Unit Position. If the search unit position within the scanner has changed more than $^1/_{16}$ in. (1.5 mm), all data since the last valid search unit position check shall be marked void and the area covered by the voided data shall be reexamined. This requirement does not apply when the requirements of VIII-434.1(a) are met.

VIII-470 EXAMINATION

VIII-471 GENERAL EXAMINATION REQUIREMENTS

VIII-471.1 Examination Coverage. The volume to be scanned shall be examined per the scan plan.

VIII-471.3 Rate of Search Unit Movement. The rate of search unit movement shall not exceed that qualified.

VIII-471.4 Scanning Sensitivity Level. The scanning sensitivity level shall not be less than that qualified.

VIII-480 EVALUATION

VIII-482 EVALUATION LEVEL

VIII-482.2 Nondistance–Amplitude Techniques. All indication images that have indicated lengths greater than the following shall be evaluated in terms of the acceptance criteria of the referencing Code Section:

(a) 0.15 in. (4 mm) for welds in material equal to or less than $1^1/_2$ in. (38 mm) thick

(b) 0.20 in. (5 mm) for welds in material greater than $1^1/_2$ in. (38 mm) thick but less than 4 in. (100 mm) thick

(c) $0.05T$ or $^3/_4$ in. (19 mm), whichever is less, for welds in material greater than 4 in. (100 mm). (T = nominal material thickness adjacent to the weld.)

For welds joining two different thicknesses of material, material thickness shall be based on the thinner of the two materials.

VIII-483 EVALUATION OF LAMINAR REFLECTORS

Reflectors evaluated as laminar reflectors in the base material which interfere with the scanning of the examination volume shall require the scan plan to be modified such that the maximum feasible volume is examined and shall be noted in the record of the examination (T-493).

VIII-485 EVALUATION SETTINGS

Final flaw evaluation shall only be made after all display parameter adjustments (e.g., contrast, brightness, and, if applicable, lateral and backwall removal and SAFT processing, etc.) have been completed.

VIII-486 SIZE AND CATEGORY

VIII-486.1 Size. The dimensions of the flaw shall be determined by the rectangle that fully contains the area of the flaw.

(a) The length of the flaw shall be the dimension of the rectangle that is parallel to the inside pressure-retaining surface of the component.

(b) The height of the flaw shall be the dimension of the rectangle that is normal to the inside pressure-retaining surface of the component.

VIII-486.2 Category. Flaws shall be categorized as being surface or subsurface based on their separation distance from the nearest component surface.

(a) If the space is equal to or less than one-half the height of the flaw, then the flaw shall be categorized as a surface flaw.[11]

(b) If the space is greater than one-half the height of the flaw, then the flaw shall be categorized as a subsurface flaw.

VIII-487 SUPPLEMENTAL MANUAL TECHNIQUES

Flaws detected during the automated or semiautomated scan may be alternatively evaluated, if applicable, by supplemental manual techniques.

VIII-488 EVALUATION BY MANUFACTURER

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed scan data to assure compliance with the requirements of Article 4, this Appendix, and the referencing Code Section. Acceptance shall be completed prior to presentation of the scan data and accompanying documentation to the Inspector.

VIII-490 DOCUMENTATION

(19) VIII-492 EXAMINATION RECORDS

The required information of T-490 and the following information shall be recorded:

(a) scan plan (including qualified range of variables)

(b) scanner and adhering and guiding mechanism

(c) indication data, that is, position in weld, length, through-wall extent, and surface or subsurface characterization

(d) the final display processing levels

(e) supplemental manual technique(s) indication data, if applicable [same information as (c)]

(f) instrument settings to include, as a minimum, excitation pulse type, duration and voltage settings, digitization rate (e.g., nominal rate as affected by compression and points quantity), rectification, pulse repetition rate, range start and stop, band pass filters, smoothing, focal type, and length

(g) focal law parameters, including, as applicable, angle or angular range, focal depth and plane, element numbers used, angular or element incremental change, and start and stop element numbers or start element number

MANDATORY APPENDIX IX
PROCEDURE QUALIFICATION REQUIREMENTS FOR FLAW SIZING AND CATEGORIZATION

IX-410 SCOPE

This Mandatory Appendix provides requirements for the qualification[12] of ultrasonic examination procedures when flaw sizing (i.e., length and through-wall height) and categorization (i.e., surface or subsurface) determination are specified for fracture-mechanics-based acceptance criteria.

IX-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

IX-430 EQUIPMENT

IX-435 DEMONSTRATION BLOCKS

IX-435.1 General. The following Article 4 paragraphs apply to demonstration blocks: T-434.1.2, T-434.1.3, T-434.1.4, T-434.1.5, T-434.1.6, and T-434.1.7.

IX-435.2 Preparation. A demonstration block shall be prepared by welding or, provided the acoustic properties are similar, the hot isostatic process (HIP) may be used.

IX-435.3 Thickness. The demonstration block shall be within 25% of the thickness to be examined. For welds joining two different thicknesses of material, demonstration block thickness shall be based on the thinner of the two materials.

IX-435.4 Weld Joint Configuration. The demonstration block's weld joint geometry shall be representative of the production joint's details, except when performing TOFD examinations of equal thickness butt welds in accordance with Mandatory Appendix III.

IX-435.5 Flaw Location. Unless specified otherwise by the referencing Code Section, the demonstration block shall contain a minimum of three actual planar flaws or three EDM notches oriented to simulate flaws parallel to the production weld's axis and major groove faces. The flaws shall be located at or adjacent to the block's groove faces as follows:

(a) one surface flaw on the side of the block representing the component O.D. surface

(b) one surface flaw on the side of the block representing the component I.D. surface

(c) one subsurface flaw

When the scan plan to be utilized subdivides a weld into multiple examination zones, a minimum of one flaw per zone is required.

IX-435.6 Flaw Size. Demonstration block flaw sizes shall be based on the demonstration block thickness and shall be no larger than that specified by the referencing Code Section

(a) maximum acceptable flaw height for material less than 1 in. (25 mm) thick, or

(b) for material equal to or greater than 1 in. (25 mm) thick, an aspect ratio of

(1) 0.25 for surface flaws

(2) 0.25 (a/l) or 0.50 (h/l), as applicable, for subsurface flaws

NOTE: a/l aspect ratios are used by Sections I and VIII. h/l aspect ratios are used by Section B31.

IX-435.7 Single I.D./O.D. Flaw Alternative. When the demonstration block can be scanned from both major surfaces during the qualification scan [e.g., joint I.D. and O.D. have a similar detail, diameter of curvature is greater than 20 in. (500 mm), no cladding or weld overlay present, etc.], then only one surface flaw is required.

IX-435.8 One-Sided Exams. When, due to obstructions, the weld examination can only be performed from one side of the weld axis, the demonstration block shall contain two sets of flaws, one set on each side of the weld axis. When the demonstration block can be scanned from both sides of the weld axis during the qualification scan (e.g., similar joint detail and no obstructions), then only one set of flaws is required.

IX-440 MISCELLANEOUS REQUIREMENTS

IX-442 QUALIFICATION DATA

The demonstration block shall be scanned and the qualification data saved per the procedure being qualified and shall be available to the Inspector and Owner/User along with a copy of any software necessary to view the data.

IX-480 EVALUATION

IX-481 SIZE AND CATEGORY

Flaws shall be sized and categorized in accordance with the written procedure being qualified.

IX-482 AUTOMATED AND SEMIAUTOMATED ACCEPTABLE PERFORMANCE CRITERIA

Acceptable performance shall be as specified by the referencing Code Section. When the referencing Code Section does not specify the acceptable performance, the following shall apply:

(a) detection of all the flaws in the demonstration block

(b) recorded responses or imaged lengths, as applicable, exceed the specified evaluation criteria of the procedure being demonstrated

(c) the flaws are properly categorized (i.e., surface or subsurface)

(d) the flaw's determined size is equal to or greater than its true size, both length and height

(e) the flaw's determined length or height is not oversized by more than 50%

IX-483 SUPPLEMENTAL MANUAL TECHNIQUE(S) ACCEPTABLE PERFORMANCE

Demonstration block flaws may be sized and categorized by a supplemental manual technique(s) outlined in the procedure, only if the automated or semiautomated flaw recorded responses meet the requirements of IX-482(a) and/or it is used for the detection of transverse reflectors. Acceptable performance, unless specified by the User or referencing Code, is defined as the demonstration block's flaws being

(a) sized as being equal to or greater than their actual size (i.e., both length and height)

(b) properly categorized (i.e., surface or subsurface)

IX-490 DOCUMENTATION

IX-492 DEMONSTRATION BLOCK RECORD

The following information shall be recorded:

(a) the information specified by the procedure being qualified

(b) demonstration block thickness, joint geometry including any cladding or weld overlays, and flaw data [i.e., position in block, size (length and height)], separation distance to nearest surface, category (surface or subsurface)

(c) scanning sensitivity and search unit travel speed

(d) qualification scan data

(e) flaw sizing data [same information as flaw data in (b)]

(f) supplemental manual technique(s) sizing data, if applicable [same information as flaw data in (b)]

MANDATORY APPENDIX X
ULTRASONIC EXAMINATION OF HIGH DENSITY POLYETHYLENE

X-410 SCOPE

This Appendix describes requirements for the examination of butt fusion welds in high density polyethylene (HDPE) pipe using encoded pulse echo, phased array, or time of flight diffraction (TOFD) ultrasonic techniques.

X-420 GENERAL

The requirements of Article 4, Mandatory Appendix III and Mandatory Appendix V, apply except as modified by this Appendix.

X-421 WRITTEN PROCEDURE REQUIREMENTS

X-421.1 Requirements. The examination shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements of Table T-421, Table X-421, and as applicable, Table III-421 or Table V-421. The written procedure shall establish a single value, or range of values, for each requirement.

X-421.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-421, Table X-421, and as applicable, Table III-421 or Table V-421 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

Table X-421
Requirements of an Ultrasonic Examination Procedure for HDPE Techniques

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Scan plan	X	...
Examination technique(s)	X	...
Computer software and revision	X	...
Scanning technique (automated versus semiautomated)	X	...
Flaw characterization methodology	X	...
Flaw sizing (length) methodology	X	...
Scanner (manufacturer and model) adhering and guiding mechanism	X	...

X-422 SCAN PLAN

A scan plan (documented examination strategy) shall be provided showing search unit placement and movement that provides a standardized and repeatable methodology for the examination. In addition to the information in Table T-421, and as applicable, Table III-421 or Table V-421, the scan plan shall include beam angles and directions with respect to the weld axis reference point, weld joint geometry, and examination area(s) or zone(s).

X-430 EQUIPMENT

X-431 INSTRUMENT REQUIREMENTS

X-431.1 Instrument. When performing phased array ultrasonic examination, T-431 and the following requirements shall apply:

(a) An ultrasonic array controller shall be used.

(b) The instrument shall be capable of operation at frequencies over the range of at least 1 MHz to 7 MHz and shall be equipped with a stepped gain control in units of 2 dB or less and a maximum gain of at least 60 dB.

(c) The instrument shall have a minimum of 32 pulsers.

(d) The digitization rate of the instrument shall be at least 5 times the search unit center frequency.

(e) Compression setting shall not be greater than that used during qualification of the procedure.

X-431.2 Data Display and Recording. When performing phased array ultrasonic examination, the following shall apply:

(a) The instrument shall be able to select an appropriate portion of the time base within which A-scans are digitized.

(b) The instrument shall be able to display A-, B-, C-, D-, and S-scans in a color palette able to differentiate between amplitude levels.

(c) The equipment shall permit storage of all A-scan waveform data, with a range defined by gates, including amplitude and time-base details.

(d) The equipment shall store positional information indicating the relative position of the waveform with respect to adjacent waveform(s), i.e., encoded position.

X-432 SEARCH UNITS

When performing phased array ultrasonic examination, the following shall apply:

(a) The nominal frequency shall be from 1 MHz to 7 MHz unless variables, such as production crystalline microstructure, require the use of other frequencies to assure adequate penetration or better resolution.

(b) Longitudinal wave mode shall be used.

(c) The number of elements used shall be between 32 and 128.

(d) Search units with angled wedges may be used to aid coupling of the ultrasound into the inspection area.

X-434 CALIBRATION BLOCKS

X-434.1 General.

X-434.1.1 Reflectors. The reference reflector shall be a side-drilled hole (SDH) with a maximum diameter of 0.080 in. (2 mm).

X-434.1.2 Material. The block shall be fabricated from pipe of the same material designation as the pipe material to be examined.

X-434.1.3 Quality. In addition to the requirements of T-434.1.3, areas that contain indications that are not attributable to geometry are unacceptable, regardless of amplitude.

X-434.3 Piping Calibration Blocks. The calibration block as a minimum shall contain $^1/_4T$ and $^3/_4T$ SDHs where T is the calibration block thickness. The calibration block shall be at least as thick as the pipe being examined. The block size and reflector locations shall allow for the calibration of the beam angles used that cover the volume of interest.

X-460 CALIBRATION

X-462 GENERAL CALIBRATION REQUIREMENTS

X-462.6 Temperature. The temperature differential between the original calibration and examination surfaces shall be within 18°F (10°C).

X-464 CALIBRATION FOR PIPING

X-464.1 System Calibration for Distance–Amplitude Techniques.

X-464.1.1 Calibration Block(s). Calibrations shall be performed utilizing the calibration block referenced in X-434.3.

X-464.1.2 Straight Beam Calibration. Straight beam calibration is not required.

X-464.2 System Calibration for Non-Distance Amplitude Techniques. Calibrations include all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination. Calibration shall be by use of the calibration block specified in X-434.3.

X-467 CALIBRATION CONFIRMATION

X-467.1 System Changes. When any part of the examination system is changed, a calibration check shall be made on the calibration block to verify that distance range point and sensitivity setting(s) of the calibration reflector with the longest sound path used in the calibration satisfy the requirements of X-467.3.

X-467.2 Calibration Checks. A calibration check on at least one of the reflectors in the calibration block or a check using a simulator shall be performed at the completion of each examination or series of similar examinations, and when examination personnel (except for automated equipment) are changed. The distance range and sensitivity values recorded shall satisfy the requirements of X-467.3.

X-467.2.1 Material Verification. When examining material from a different production lot from that of the calibration block, a verification of the material velocity shall be made using a machined radius on a block manufactured from the new lot and any difference in the results be compensated for in both velocity and gain level.

X-467.2.2 Temperature Variation. If during the course of the examination, the temperature differential between the calibration block used during the most recent calibration and examination surface varies by more than 18°F (10°C), recalibration is required.

NOTE: Interim calibration checks between the required initial calibration and the final calibration check may be performed. The decision to perform interim calibration checks should be based on ultrasonic instrument stability (analog vs. digital), the risk of having to conduct reexaminations, and the benefit of not performing interim calibration checks.

X-467.3 Confirmation Acceptance Values.

X-467.3.1 Distance Range Points. If the distance range point for the deepest reflector used in the calibration has moved by more than 10% of the distance reading or 5% of full sweep, whichever is greater, correct the distance range calibration and note the correction in the examination record. All recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or rerecorded.

X-467.3.2 Sensitivity Settings. If the sensitivity setting for the deepest reflector used in the calibration has changed by less than 4 dB, compensate for the difference when performing the data analysis and note the correction in the examination record. If the sensitivity setting has changed by more than 4 dB, the examination shall be repeated.

X-470 EXAMINATION

X-471 GENERAL EXAMINATION REQUIREMENTS

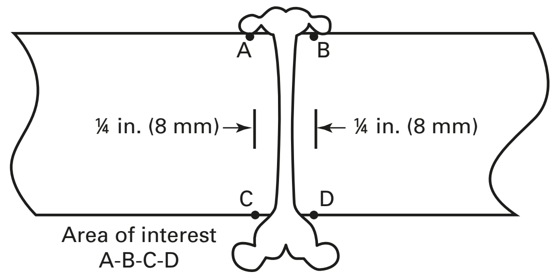
X-471.1 Examination Coverage. The examination volume shall be as shown in Figure X-471.1 below.

X-471.6 Recording. A-scan data shall be recorded for the area of interest in a form consistent with the applicable Code Section requirement, and recording increments with a maximum of

(a) 0.04 in. (1 mm) for material less than 3 in. (75 mm) thick

(b) 0.08 in. (2 mm) for material greater than 3 in. (75 mm) thick

Figure X-471.1
Fusion Pipe Joint Examination Volume



X-490 DOCUMENTATION

X-492 EXAMINATION RECORD

A-scan recorded data need only be retained until final flaw evaluation has been performed or as specified by the referencing Code Section.

(19)

MANDATORY APPENDIX XI FULL MATRIX CAPTURE

XI-410 SCOPE

This Appendix provides the requirements for using the full matrix capture (FMC) ultrasonic technique, in conjunction with data reconstruction techniques, when examinations are performed for fracture-mechanics-based acceptance criteria. A general description of FMC data and data reconstruction techniques is given in Article 4, Nonmandatory Appendix F.

XI-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

XI-421 WRITTEN PROCEDURE REQUIREMENTS

XI-421.1 Requirements. The examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table XI-421.1-1. Due to unique processes or equipment, essential variables that are not identified in Table XI-421.1-1 shall also be addressed in the procedure, and a single value or range of values shall be established for each essential variable. An essential variable is an equipment or software setting that influences the ultrasonic signal as displayed, recorded, or automatically processed.

XI-421.1.1 Software. Software revisions shall not require requalification unless any change(s) have been made that would influence the ultrasonic signal as displayed, recorded, or automatically processed. Software revisions shall be documented and available for review.

XI-421.2 Procedure Qualification. Procedure qualification is required per Article 4, Mandatory Appendix IX and shall comply with Article 1, T-150(d). The requirements of Table XI-421.1-1 shall apply.

XI-422 SCAN PLAN

A scan plan shall be required that provides a standardized and repeatable methodology for the examination. As a minimum, the scan plan shall include a depiction of the required examination volume coverage, imaging paths, image grid density, weld joint geometry, number of examination scan lines, and search unit placement and movement with respect to the weld axis and zero-datum point.

XI-423 PERSONNEL QUALIFICATIONS

In addition to the requirements of Article 1, Mandatory Appendix II, only qualified ultrasonics (UT) personnel who are trained in the use of the equipment and who have demonstrated the ability to properly acquire examination data, approve setups, and perform calibrations shall conduct production scans. Personnel who perform data reconstruction techniques, in real time or as post-processed images, or analyze and interpret data, shall be Level II or Level III examiners with documented training and demonstrated proficiency in the use of the equipment and software. The training and demonstration requirements shall be addressed in the employer's written practice.

XI-430 EQUIPMENT

XI-432 SEARCH UNIT(S)

Search unit(s) used for examination shall be the same [i.e., manufacturer, model number, and physical configuration, including wedge(s)] as those used during qualification.

XI-432.4 Search Unit Performance. The amplitude response from 75% of the individual elements within the aperture shall fall within 3 dB. The amplitude response from the remaining 25% of the individual elements shall fall within 6 dB. Elements found outside these parameters shall be considered inactive. The number of inactive elements within an aperture shall not exceed 1 element for every 16 elements, with no 2 being adjacent. Exceptions to this requirement shall be demonstrated and documented during the qualification.

XI-434 CALIBRATION BLOCKS

XI-434.1 General. A calibration block meeting the requirements of Figure XI-434.1-1 shall be used, and shall also meet the requirements of T-434.1.2 through T-434.1.6. Alternatively, existing calibration blocks described in T-434 may be used, provided one of the following applies:

(a) Notch, slot, and side-drilled holes (SDHs) meeting the requirements of Figure XI-434.1-1 are embedded.

(b) Notch and slot reflectors meeting the requirements of Figure XI-434.1-1 are embedded and a known reference standard described in XI-435 with SDHs meeting the requirements of XI-462.8.1 is used.

Table XI-421.1-1
Requirements of an FMC Examination Procedure

Requirements	Essential Variable	Nonessential Variable
Weld configurations to be examined, including thickness dimensions and base material product form (pipe, plate, etc.)	X	...
The surfaces from which the examination shall be performed	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...
Calibration [calibration block(s) and technique(s)]	X	...
Method for discriminating geometric from flaw indications	X	...
Personnel performance requirements, when required	X	...
Instrument manufacturer and model	X	...
Computer software version	X	...
Search unit(s) manufacturer and model (element pitch, size, number, frequency, and gap dimensions)	X	...
Wedge dimensional description [i.e., cut angle, *x* and *z* dimensions, and material contouring (if any)]	X	...
Examination volume	X	...
Method of achieving amplitude fidelity	X	...
Description of the frame (i.e., temporal range, density)	X	...
Description of the post-processed grid (i.e., height, width, density)	X	...
Image reconstruction techniques	X	...
Scan plan	X	...
Scanner manufacturer and model	X	...
Scanning technique (automated vs. semiautomated)	X	...
Scanning and adhering and guiding mechanism	X	...
Flaw sizing (length and height) methodology	X	...
Weld datum reference	...	X
Personnel qualification requirements	...	X
Surface condition (examination surface, calibration block)	...	X
Couplant: brand name or type	...	X
Post-examination cleaning technique	...	X
Automatic alarm and/or recording equipment, when applicable	...	X
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X

Blocks may be flat or curved. When they are curved, the requirements of T-434.1.7 shall also apply.

XI-435 REFERENCE STANDARDS

Known reference standards (e.g., IIW, IIW PA Block Type A, ASTM E2491, ISO 19675) shall be used to establish instrument range and delay.

XI-450 TECHNIQUES

Contact or immersion techniques may be used.

XI-451 DATA RECONSTRUCTION TECHNIQUES

Algorithms used to generate imaging paths shall be the same as those used during qualification. Multiple data reconstruction algorithms may be applied to data collected during an examination provided

(a) the reconstruction technique was successfully demonstrated using the original qualification data

(b) the data reconstruction technique is included in the written procedure

(c) the acquired examination data set can support the reconstruction technique without reacquisition

(d) the image paths were included in the calibration prior to the exam

XI-460 CALIBRATION

XI-461 AMPLITUDE FIDELITY

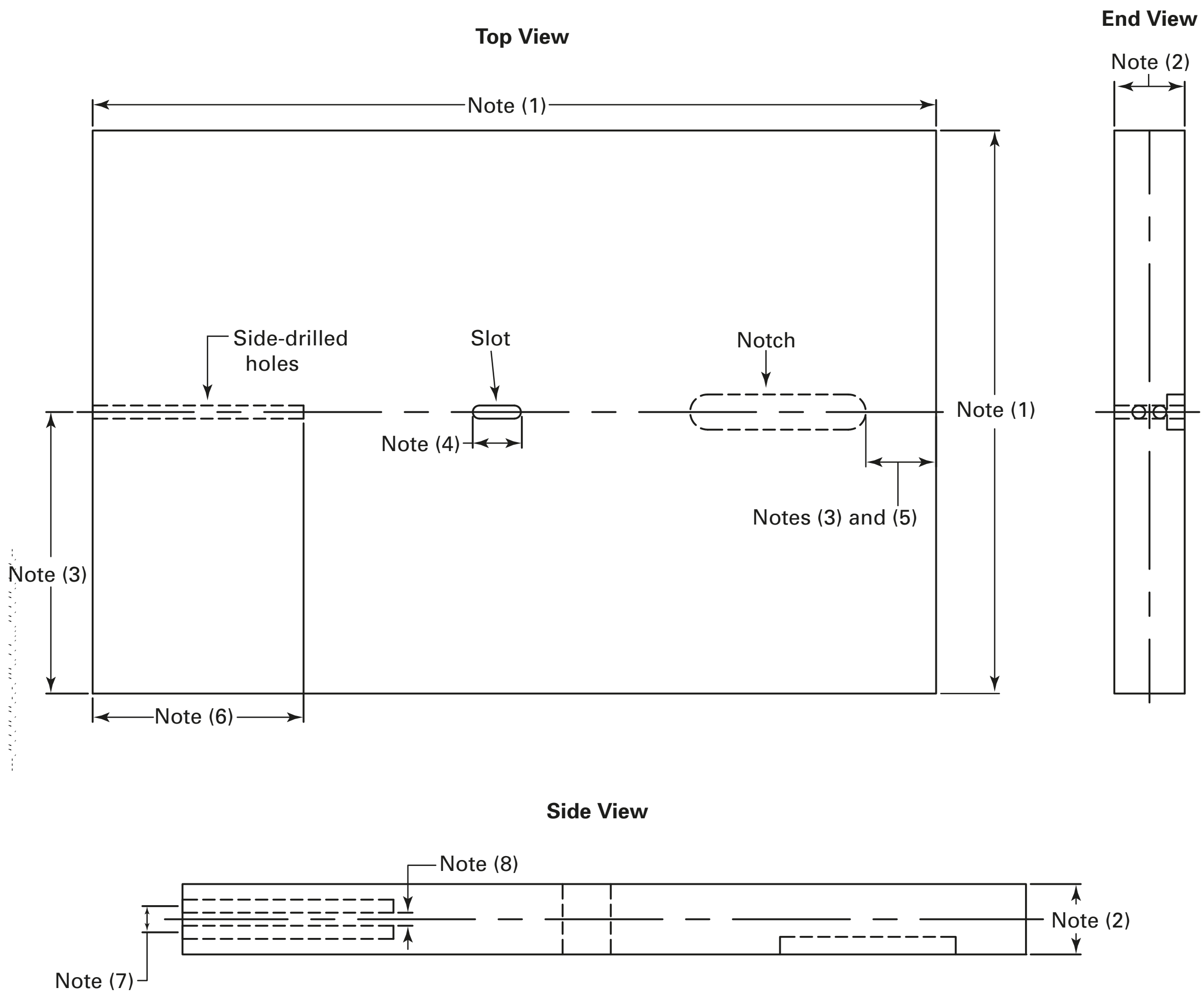
Amplitude fidelity shall be preserved to 2 dB or less. The process for achieving amplitude fidelity shall be included in the qualified procedure.

XI-462 GENERAL CALIBRATION REQUIREMENTS

XI-462.4 Contact Wedges. When contoured wedges are required by T-432.2, a curved calibration block shall be used. Alternatively, for calibration, a flat wedge(s) may be used on a flat calibration block, provided the process is documented during the qualification and the following requirements are met:

(a) The wedge dimensions that affect the transmit, receive, and display (i.e., delay and velocity) of ultrasound shall be compensated for and corrected prior to the examination.

Figure XI-434.1-1
Calibration Block



Weld Thickness, t, in. (mm)	Reference Block Thickness, T, in. (mm)	Maximum Hole Diameter, in. (mm)
Up to 1 (25)	$^3/_4$ (19) or t	$^3/_{32}$ (2.5)
Over 1 (25) through 2 (50)	$1^1/_2$ (38) or t	$^1/_8$ (3)
Over 2 (50) through 4 (100)	3 (75) or t	$^3/_{16}$ (5)
Over 4 (100)	t ± 1 (25)	[Note (9)]

GENERAL NOTE: Reflectors may be placed anywhere within the block, in any configuration, provided that they do not interfere with the ultrasonic response from the other calibration reflectors or the edges of the block.

NOTES:
(1) Physical size of the block may be any convenient configuration provided that block dimensions in width and length are of sufficient size to accommodate placement of the search unit for observation or measurement, wholly on the scanning surface, such that access to the desired reflector can be made with the full contact area of the search unit remaining on the block, without interference from the edges.
(2) Block thickness for piping shall be ±25%T. For all other components, block thickness shall be no less than 90% and no more than 120% of the average weld thickness, t. Weld thickness, t, is the nominal material thickness for welds without reinforcement or, for welds with reinforcement, the nominal material thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. When two or more base material thicknesses are involved, the calibration block thickness, T, shall be determined by the average thickness of the weld; alternatively, a calibration block based on the greater base material thickness may be used, provided the reference reflector size is based on the average weld thickness.
(3) The notch and slot shall not be placed in proximity to the edges of the block such that the edge may diminish or interfere with the ultrasonic response.

Figure XI-434.1-1
Calibration Block (Cont'd)

NOTES (CONT'D):
(4) The slot (i.e., through-wall notch) shall be inserted approximately perpendicular to the examination surface and through the entire block thickness. The slot shall have a maximum reflecting surface width of 0.25 in. (6 mm) for blocks less than 2 in. (50 mm) in thickness; slot width may increase 0.125 in. (3 mm) for each additional 1 in. (25 mm) of block thickness, or fraction thereof, for blocks greater than 2 in. (50 mm) in thickness.
(5) Notch depth shall be no greater than 11%T. All notches shall be 1 in. (25 mm) minimum in length. Notch width shall not exceed 0.25 in. (6 mm).
(6) The SDHs shall be drilled a minimum of 1.5 in. (38 mm) deep approximately parallel to the examination surface.
(7) The SDHs shall be aligned perpendicularly, in depth, through the block thickness at a separation distance of two times their diameter, as measured center-to-center.
(8) The placement of the SDHs shall span the centerline of the block thickness such that one SDH resides on either side of the centerline of the block thickness.
(9) For each increase in weld thickness of 2 in. (50 mm), or fraction thereof, over 4 in. (100 mm), the hole diameter shall increase $^1/_{16}$ in. (1.5 mm).

(b) The flat wedges are manufactured from the same material, and all physical dimensions (other than contour), including height from the contact surface to the slope of the wedge, are the same, within the manufacturer's tolerance(s).

(c) The flat wedge(s) shall not be used for examination.

(d) Verification prior to the examination shall be performed with the contoured wedge(s) to be used for the examination. The verification shall use an identical reflector established in XI-464.2, in a suitably curved block [i.e., within the component curvature contour selection criteria established from T-432.2(b)(1) or T-432.2(b)(2)] and shall fall within 10% of amplitude and material depth.

XI-462.5 System Delay and Velocity. Instrument delay and velocity settings may be adjusted on the specific component at the time of examination provided the process was used during the qualification and is included in the procedure.

XI-462.8 Performance Verification. Prior to examination(s), the system shall be verified as described in XI-462.8.1 through XI-462.8.3.

XI-462.8.1 Resolution Verification. System resolution shall be considered satisfactory upon demonstrating its ability to image the spatial distance between the SDHs in the calibration block. Alternatively, the SDHs of a known reference standard described in XI-435 (e.g., IIW PA Block Type A, ASTM E2491) may be used provided that the depth of the holes falls within the middle third of the examination volume.

XI-462.8.2 Path(s) Verification. The entire through-wall height of the slot shall be imaged by placing the search unit such that the slot is imaged at a distance beyond the centerline of the weld or, when using tandem search units, an opposing search unit shall be placed on either side of the slot such that the slot position would be imaged equidistant from the search units. Amplitude deviation shall not exceed 6 dB along the entire height of the slot.

XI-462.8.3 Sizing Verification. The length and height of the notch shall be imaged and sized. The imaged dimension of the notch shall not be less than its actual known height or length. It shall also not exceed the lesser of 50% or 0.150 in. (4 mm) of the known height, and shall not exceed 50% of the known length.

XI-464

XI-464.2 Sensitivity. Calibration sensitivity shall be established by recording the imaged intensity of an SDH described in XI-462.8.1 to a level greater than or equal to 50% full screen height (FSH), and shall not exhibit saturation. Other reflectors (i.e., entry surface, backwall) may exhibit saturation.

XI-467 ENCODER CALIBRATION

A calibration check shall be performed at intervals not to exceed one month or prior to first use thereafter, by moving the encoder a minimum distance of 20 in. (500 mm). The displayed distance shall be within 1% of the actual distance moved.

XI-467.1 Equipment Confirmation Checks. The examination system shall be verified for compliance with XI-432.4 and XI-461 prior to initial calibration(s) and at the conclusion of an examination or series of examinations.

XI-470 EXAMINATION

XI-471 GENERAL EXAMINATION REQUIREMENTS

XI-471.1 Examination Coverage. The volume to be examined shall be scanned using a linear scanning technique with an encoder per the scan plan. Adherence to the scan plan and the capture of the required examination volume shall be verified prior to evaluation.

XI-471.1.1 Image Paths. The imaging paths used during calibration shall be the same as those for the examination.

XI-471.2 FMC Frame. To fulfill the amplitude fidelity requirement in XI-461, the frame shall have enough temporal range to encompass the examination volume and density when combined with the reconstruction process.

XI-471.3 Scanning. Each linear scan shall be parallel to the weld axis.

(a) The search unit shall be maintained at a fixed distance from the weld axis by a fixed guide or mechanical means.

(b) Scanning speed shall be such that data drop-out is less than 2 data lines/in. (25 mm) of the linear scan length and there are no adjacent data line skips

(c) When multiple linear scans are needed to cover the required volume, a maximum overlap of 50% of the active aperture shall be maintained.

XI-471.6 Recording. Data frame collection increments for linear scanning shall not exceed the following:

(a) 0.04 in. (1 mm) for material <3 in. (75 mm) thick

(b) 0.08 in. (2 mm) for material ≥3 in. (75 mm) thick

XI-471.7 Reflectors Transverse to the Weld Seam. Alternative ultrasonic techniques may be performed for reflectors transverse to the weld axis.

XI-474

XI-474.1 Examination Sensitivity. Examination sensitivity shall not be less than that established during calibration. However, sensitivity may be adjusted on the actual component, provided that the methodology and component reflector used are identified (e.g., backwall), and the upper and lower limits of the sensitivity range are qualified. The process for this qualification shall be included in the procedure.

XI-480 EVALUATION

XI-481 GENERAL EVALUATION REQUIREMENTS

XI-481.1 Imaging Paths. Imaging path(s) identified in XI-462.8.1 shall encompass, either individually or in combination, the entire examination volume. Coverage shall be determined by the area contained within −6 dB of beam divergence from all contributing elements.

XI-481.1.1 Direct Paths. Direct imaging paths (i.e., L–L or T–T) alone shall not be considered adequate for full volume examination.

XI-481.1.2 Data Density. The spatial resolution of data points within the imaged grid (i.e., pixel spacing and nodes) shall comply with XI-461 as a minimum, and shall not exceed 1% of component thickness. For components joining two different material thicknesses, component thickness shall be based on the thinner of the two materials. Spatial resolution within the grid shall not be greater than that used during qualification.

XI-481.2 Component Volume Correction. All images shall be corrected for component thickness and geometry prior to evaluation. The technique used (e.g., adaptive algorithms) for component volume correction shall be included in the qualified procedure.

XI-481.4 Ultrasonic Image Artifacts. Artifacts produced on the image are permissible provided that they do not interfere with the disposition of an indication. A determination of the origin of the artifact(s) shall be made.

XI-482 EVALUATION LEVEL

All indication images that have indicated lengths greater than the following shall be evaluated in terms of the acceptance criteria of the referencing Code Section:

(a) 0.15 in. (4 mm) for welds in material equal to or less than $1^1/_2$ in. (38 mm) thick

(b) 0.20 in. (5 mm) for welds in material greater than $1^1/_2$ in. (38 mm) thick but less than 4 in. (100 mm) thick

(c) $0.05T$ or $^3/_4$ in. (19 mm), whichever is less, for welds in material greater than 4 in. (100 mm), where T is the nominal material thickness adjacent to the weld

For welds joining two different thicknesses of material, material thickness shall be based on the thinner of the two materials.

XI-483 EVALUATION OF LAMINAR REFLECTORS

Indications that are characterized as laminar reflectors in the base material, which would interfere with the propagation of ultrasound in the examination volume, shall require the scan plan to be modified such that the maximum feasible volume is examined, and this shall be noted in the record of the examination.

XI-485 EVALUATION SETTINGS

Final flaw evaluation shall only be made after all display parameter adjustments have been completed.

XI-486 SIZE AND CATEGORY

XI-486.1 Size. The dimensions of the flaw shall be determined by the rectangle that fully contains the area of the flaw.

(a) The length of the flaw shall be the dimension of the rectangle that is parallel to the inside pressure-retaining surface of the component.

(b) The height of the flaw shall be the dimension of the rectangle that is normal to the inside pressure-retaining surface of the component.

XI-486.2 Category. Flaws shall be categorized as being surface or subsurface based on their separation distance from the nearest component surface.

(a) If the separation distance is equal to or less than one-half the height of the flaw, then the flaw shall be categorized as a surface flaw.

(b) If the separation distance is greater than one-half the height of the flaw, then the flaw shall be categorized as a subsurface flaw.

XI-488 EVALUATION BY MANUFACTURER

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed examination to ensure compliance with the requirements of Article 4, this Appendix, and the referencing Code Section. Acceptance shall be completed prior to presentation of the scan data and accompanying documentation to the Inspector.

XI-490 DOCUMENTATION

XI-492 EXAMINATION RECORDS

For each FMC examination, the requirements of Article 1, T-150(d), T-190(a), T-491, and the following information shall be recorded:

(a) the manufacturer name, number of channels, and serial number of the instrument

(b) the manufacturer's model and serial numbers, type, frequency, element size and number, elevation, and pitch and gap (spacing between active elements) dimensions of the array

(c) the wedge material or velocity, cut angle, or the natural refracted angle in examined material, and contouring when used; for non-integral wedges, the description shall include x and y dimensions

(d) the brand name or type of the couplant used

(e) the type and length of the search unit cable(s) used

(f) the scanner type (per T-453) and the adhering and guiding mechanism

(g) identification of all examination-related computerized program(s) including software revision(s)

(h) identification of the calibration block and reference standards when used

(i) as a minimum, the following instrument settings:

(1) excitation pulse type

(2) duration and voltage settings

(3) digitization rate (e.g., nominal rate as affected by compression and points quantity)

(4) pulse repetition rate

(5) range start and stop

(6) band pass filters

(7) smoothing

(j) instrument reference level gain and, if used, damping and reject setting(s)

(k) calibration data [including reference reflector(s)] and response(s) for resolution, paths, sizing, and sensitivity

(l) data correlating simulation block(s) and electronic simulator(s), when used, with initial calibration

(m) identification of adaptive or corrective algorithms when used

(n) frame type [e.g., synthetic aperture focusing technique (SAFT), FMC] and frame definition (i.e., size, resolution), and identification of data saved or image only

(o) post-processing technique (e.g., DAS, migration), grid definition (i.e., size, resolution), imaging path(s) used, adjustment applied (i.e., grid correction, adaptive algorithms, amplitude normalization, software gain), including the final display-processing levels

(p) identification and location of the weld or volume scanned

(q) surface(s) from which the examination was conducted, including surface condition

(r) a map or record of indications detected or areas cleared, including indication data (i.e., position in weld, length, through-wall extent, and surface or subsurface characterization)

(s) supplemental manual technique(s) indication data, if applicable [same information as (r)]

(t) areas of restricted access or inaccessible welds

(u) scan plan and variables to include search unit orientation, scanning increments (scan resolution), and scanning speed

Items (a) through (n) may be included or attached in a separate calibration record provided the calibration record is included in the examination record.

XI-494 DATA STORAGE

Data archives shall be in a format appropriate for future access and review. As a minimum, the original reconstructed data image(s), as well as the original imaging parameters, shall be stored.

NONMANDATORY APPENDIX A
LAYOUT OF VESSEL REFERENCE POINTS

A-410 SCOPE

This Appendix provides requirements for establishing vessel reference points.

A-440 MISCELLANEOUS REQUIREMENTS

The layout of the weld shall consist of placing reference points on the center line of the weld. The spacing of the reference points shall be in equal increments (e.g., 12 in., 3 ft, 1 m, etc.) and identified with numbers (e.g., 0, 1, 2, 3, 4, etc.). The increment spacing, number of points, and starting point shall be recorded on the reporting form. The weld center line shall be the divider for the two examination surfaces.

A-441 CIRCUMFERENTIAL (GIRTH) WELDS

The standard starting point shall be the 0 deg axis of the vessel. The reference points shall be numbered in a clockwise direction, as viewed from the top of the vessel or, for horizontal vessels, from the inlet end of the vessel. The examination surfaces shall be identified (e.g., for vertical vessels, as being either above or below the weld).

A-442 LONGITUDINAL WELDS

Longitudinal welds shall be laid out from the center line of circumferential welds at the top end of the weld or, for horizontal vessels, the end of the weld closest to the inlet end of the vessel. The examination surface shall be identified as clockwise or counterclockwise as viewed from the top of the vessel or, for horizontal vessels, from the inlet end of the vessel.

A-443 NOZZLE-TO-VESSEL WELDS

The external reference circle shall have a sufficient radius so that the circle falls on the vessel's external surface beyond the weld's fillet. The internal reference circle shall have a sufficient radius so that the circle falls within $\frac{1}{2}$ in. (13 mm) of the weld centerline. The 0 deg point on the weld shall be the top of the nozzle. The 0 deg point for welds of veritcally oriented nozzles shall be located at the 0 deg axis of the vessel, or, for horizontal vessels, the point closest to the inlet end of the vessel. Angular layout of the weld shall be made clockwise on the external surface and counterclockwise on the internal surface. The 0 deg, 90 deg, 180 deg, and 270 deg lines will be marked on all nozzle welds examined; 30 deg increment lines shall be marked on nozzle welds greater than a nominal 8 in. (200 mm) diameter; 15 deg increment lines shall be marked on nozzle welds greater than a nominal 24 in. (600 mm) diameter; 5 deg increment lines shall be marked on nozzle welds greater than 48 in. (1 200 mm) diameter.

NONMANDATORY APPENDIX B
GENERAL TECHNIQUES FOR ANGLE BEAM CALIBRATIONS

B-410 SCOPE

This Appendix provides general techniques for angle beam calibration. Other techniques may be used.

Descriptions and figures for the general techniques relate position and depth of the reflector to eighths of the V-path. The sweep range may be calibrated in terms of units of metal path,[13] projected surface distance or actual depth to the reflector (as shown in Figures B-461.1, B-461.2, and B-461.3). The particular method may be selected according to the preference of the examiner.

B-460 CALIBRATION

B-461 SWEEP RANGE CALIBRATION

B-461.1 Side Drilled Holes (See Figure B-461.1).

B-461.1.1 Delay Control Adjustment. Position the search unit for the maximum first indication from the $\frac{1}{4}T$ side-drilled hole (SDH). Adjust the left edge of this indication to line 2 on the screen with the delay control.

B-461.1.2 Range Control Adjustment.[14] Position the search unit for the maximum indication from the $\frac{3}{4}T$ SDH. Adjust the left edge of this indication to line 6 on the screen with the range control.

B-461.1.3 Repeat Adjustments. Repeat delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ SDH indications start at sweep lines 2 and 6.

B-461.1.4 Notch Indication. Position the search unit for maximum response from the square notch on the opposite surface. The indication will appear near sweep line 8.

B-461.1.5 Sweep Readings. Two divisions on the sweep now equal $\frac{1}{4}T$.

B-461.2 IIW Block (See Figure B-461.2). IIW Reference Blocks may be used to calibrate the sweep range displayed on the instrument screen. They have the advantage of providing reflectors at precise distances that are not affected by side-drilled hole location inaccuracies in the basic calibration block or the fact that the reflector is not at the side-drilled hole centerline. These blocks are made in a variety of alloys and configurations. Angle beam range calibrations are provided from the 4 in. (100 mm) radius and other reflectors. The calibration block shown in Figure B-461.2 provides an indication at 4 in. (100 mm) and a second indication from a reflection from the vertical notches at the center point 8 in. (200 mm) back to the radius and returning to the transducer when the exit point of the wedge is directly over the center point of the radius. Other IIW blocks provide

Figure B-461.1
Sweep Range (Side-Drilled Holes)

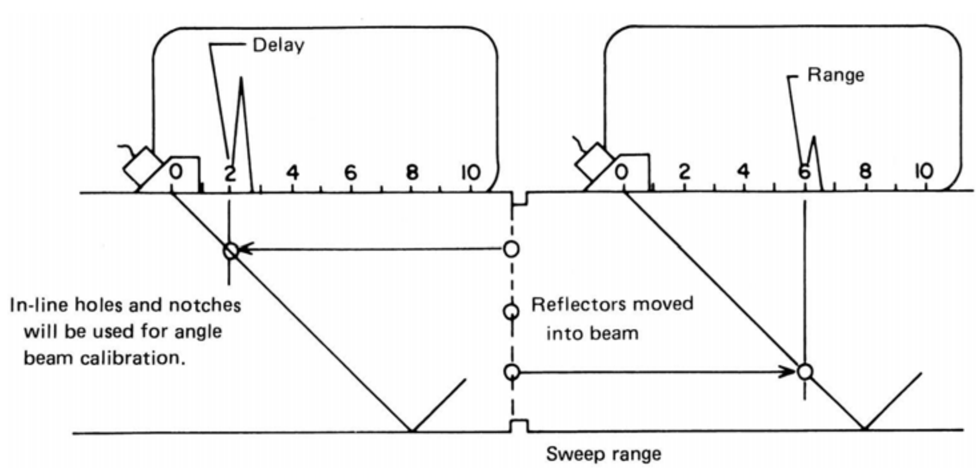
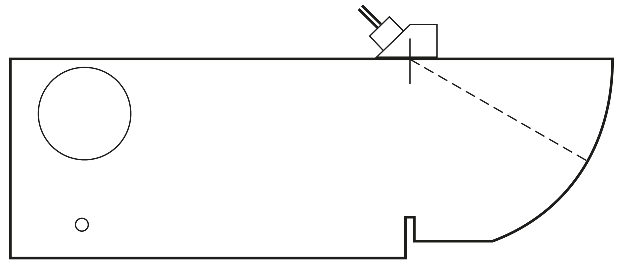


Figure B-461.2
Sweep Range (IIW Block)



signals at 2 in. (50 mm) and 4 in. (100 mm) and a third design provides indications at 4 in. (100 mm) and 9 in. (225 mm).

B-461.2.1 Search Unit Adjustment. Position the search unit for the maximum indication from the 4 in. (100 mm) radius while rotating it side to side to also maximize the second reflector indication.

B-461.2.2 Delay and Range Control Adjustment. Without moving the search unit, adjust the range and delay controls so that the indications start at their respective metal path distances.

B-461.2.3 Repeat Adjustments. Repeat delay and range control adjustments until the two indications are at their proper metal path on the screen.

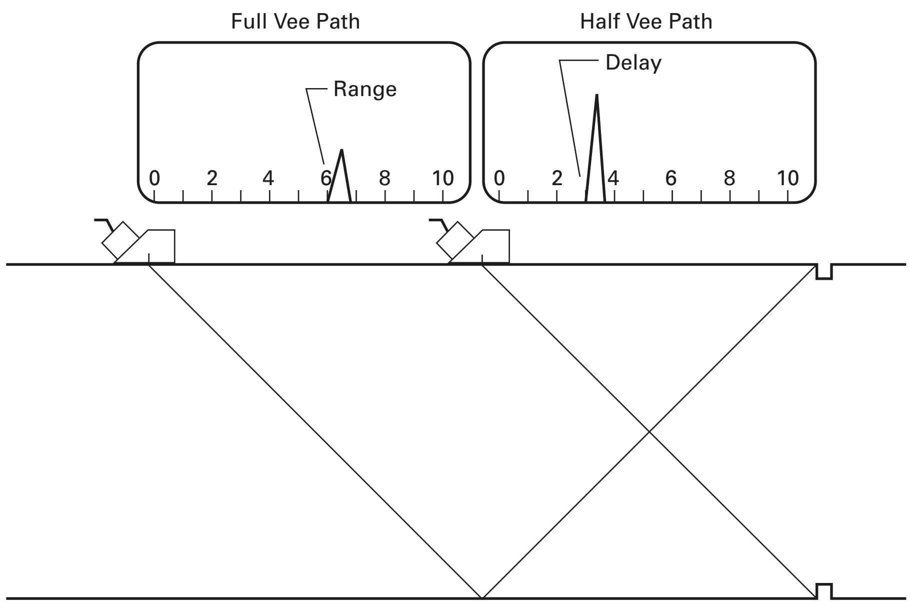
B-461.2.4 Sweep Readings. Two divisions on the sweep now equal $1/5$ of the screen range selected.

B-461.3 Piping Block (See Figure B-461.3). The notches in piping calibration blocks may be used to calibrate the distance range displayed on the instrument screen. They have the advantage of providing reflectors at precise distances to the inside and outside surfaces.

B-461.3.1 Delay Control Adjustment. Position the search unit for the maximum first indication from the inside surface notch at its actual beam path on the instrument screen. Adjust the left edge of this indication to its metal path on the screen with the delay control.

B-461.3.2 Range Control Adjustment. Position the search unit for the maximum second indication from the outside surface notch. Adjust the left edge of this indication to its metal on the screen with the range control or velocity control.

Figure B-461.3
Sweep Range (Notches)



B-461.3.3 Repeat Adjustments. Repeat delay and range control adjustments until the two indications are at their proper metal paths on the screen.

B-461.3.4 Sweep Readings. Two divisions on the sweep now equal one-fifth of the screen range selected.

B-462 DISTANCE–AMPLITUDE CORRECTION

B-462.1 Calibration for Side-Drilled Holes Primary Reference Level From Clad Side (See Figure B-462.1).

(a) Position the search unit for maximum response from the SDH, which gives the highest amplitude.

(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height (FSH). Mark the peak of the indication on the screen.

(c) Position the search unit for maximum response from another SDH.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the third SDH and mark the peak on the screen.

(f) Position the search unit for maximum amplitude from the $^{3}/_{4}T$ SDH after the beam has bounced from the opposite surface. The indication should appear near sweep line 10. Mark the peak on the screen for the $^{3}/_{4}T$ position.

(g) Connect the screen marks for the SDHs to provide the distance–amplitude curve (DAC).

(h) For calibration correction for perpendicular reflectors at the opposite surface, refer to B-465.

B-462.2 Calibration for Side-Drilled Holes Primary Reference Level From Unclad Side (See Figure B-462.1).

(a) From the clad side of the block, determine the dB change in amplitude between the $^{3}/_{4}T$ and $^{5}/_{4}T$ SDH positions.

(b) From the unclad side, perform calibrations as noted in B-462.1(a) through B-462.1(e).

(c) To determine the amplitude for the $^{5}/_{4}T$ SDH position, position the search unit for maximum amplitude from the $^{3}/_{4}T$ SDH. Decrease the signal amplitude by the number of dB determined in (a) above. Mark the height of this signal amplitude at sweep line 10 ($^{5}/_{4}T$ position).

(d) Connect the screen marks to provide the DAC. This will permit evaluation of indications down to the clad surface (near sweep line 8).

(e) For calibration correction for perpendicular planar reflectors near the opposite surface, refer to B-465.

B-462.3 Calibration for Piping Notches Primary Reference Level (See Figure B-462.3).

(a) Position the search unit for maximum response from the notch which gives the highest amplitude.

(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height (FSH). Mark the peak of the indication on the screen.

(c) Without changing the gain, position the search unit for maximum response from another notch.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the remaining notch at its Half Vee, Full Vee or $^{3}/_{2}$ Vee beam paths and mark the peak on the screen.

(f) Position the search unit for maximum amplitude from any additional Vee Path(s) when used and mark the peak(s) on the screen.

(g) Connect the screen marks for the notches to provide the distance–amplitude curve (DAC).

(h) These points also may be captured by the ultrasonic instrument and electronically displayed.

Figure B-462.1
Sensitivity and Distance–Amplitude Correction (Side-Drilled Holes)

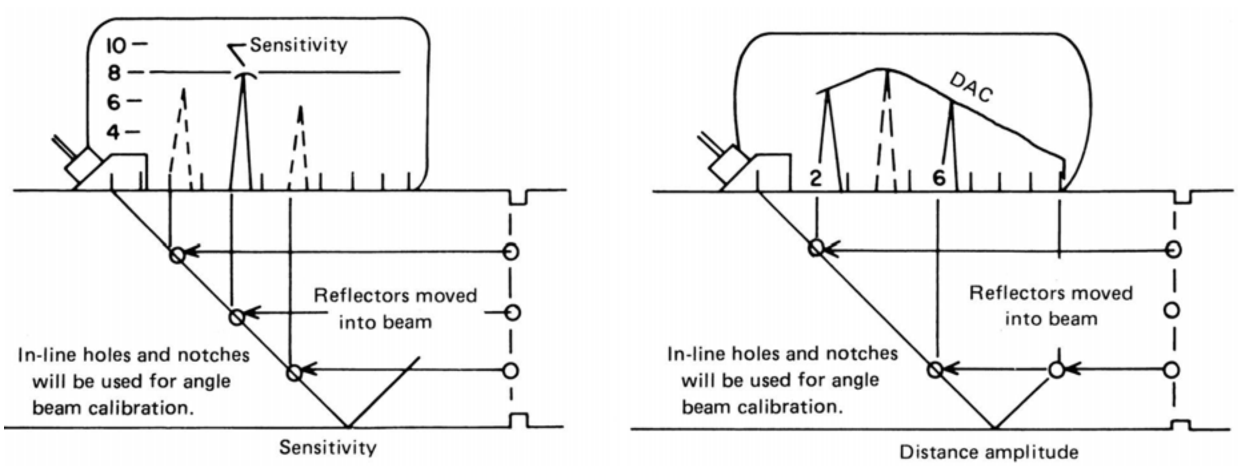
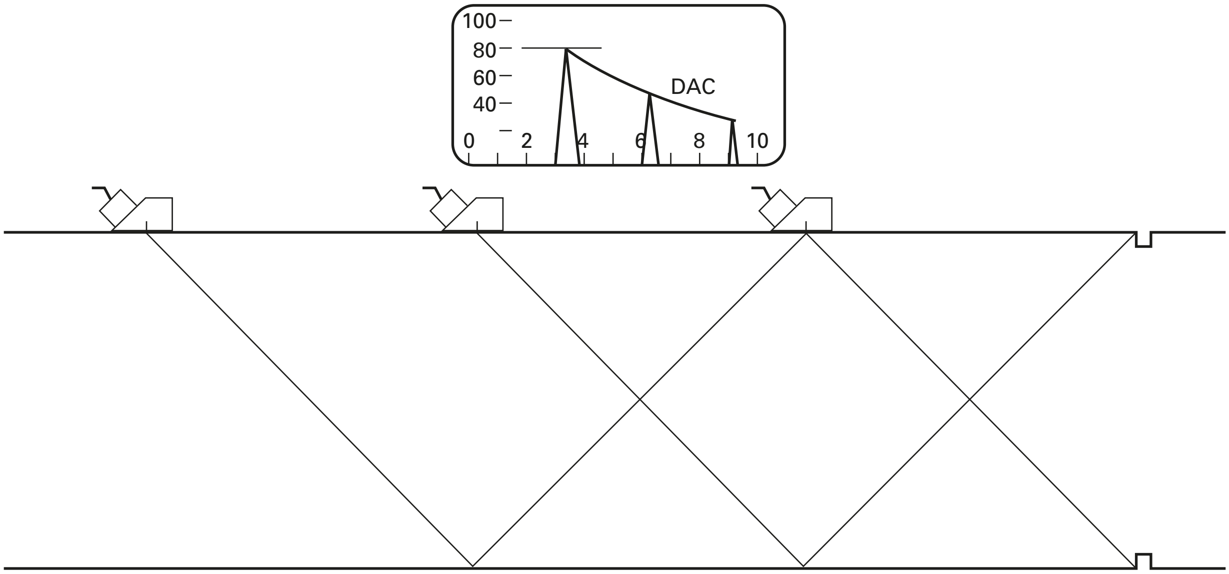


Figure B-462.3
Sensitivity and Distance–Amplitude Correction (Notches)



B-463 DISTANCE–AMPLITUDE CORRECTION INNER $^1/_4$ VOLUME (SEE NONMANDATORY APPENDIX J, FIGURE J-431 VIEW A)

B-463.1 Number of Beam Angles. The $^1/_4$ volume angle calibration requirement may be satisfied by using one or more beams as required to calibrate on $^1/_8$ in. (3 mm) maximum diameter side-drilled holes in that volume.

B-463.2 Calibration From Unclad Surface. When the examination is performed from the outside surface, calibrate on the $^1/_8$ in. (3 mm) diameter side-drilled holes to provide the shape of the DAC from $^1/_2$ in. (13 mm) to $^1/_4T$ depth. Set the gain to make the indication from $^1/_8$ in. (3 mm) diameter side-drilled hole at $^1/_4T$ depth the same height as the indication from the $^1/_4T$ depth hole as determined in B-462.1 or B-462.2 above. Without changing the gain, determine the screen height of the other near surface indications from the remaining $^1/_8$ in. (3 mm) diameter side-drilled holes from $^1/_2$ in. (13 mm) deep to the $^1/_8$ in. (3 mm) diameter side-drilled hole just short of the $^1/_4T$ depth. Connect the indication peaks to complete the near surface DAC curve. Return the gain setting to that determined in B-462.1 or B-462.2.

B-463.3 Calibration From Clad Surface. When the examination is performed from the inside surface, calibrate on the $^1/_8$ in. (3 mm) diameter side-drilled holes to provide the shape of the DAC and the gain setting, as per B-463.2 above.

B-464 POSITION CALIBRATION (SEE FIGURE B-464)

The following measurements may be made with a ruler, scale, or marked on an indexing strip.[15]

B-464.1 $^1/_4T$ SDH Indication. Position the search unit for maximum response from the $^1/_4T$ SDH. Place one end of the indexing strip against the front of the search unit, the other end extending in the direction of the beam. Mark the number 2 on the indexing strip at the scribe line which is directly above the SDH. (If the search unit covers the scribe line, the marks may be made on the side of the search unit.)

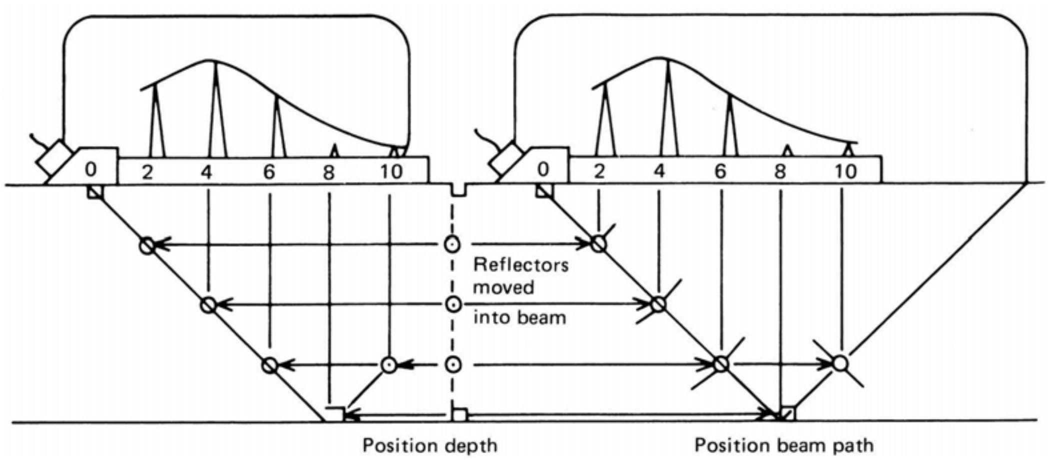
B-464.2 $^1/_2T$ and $^3/_4T$ SDH Indications. Position the search unit for maximum indications from the $^1/_2T$ and $^3/_4T$ SDHs. Keep the same end of the indexing strip against the front of the search unit. Mark the numbers 4 and 6 on the indexing strip at the scribe line, which are directly above the SDHs.

B-464.3 $^5/_4T$ SDH Indication. If possible, position the search unit so that the beam bounces from the opposite surface to the $^3/_4T$ SDH. Mark the number 10 on the indexing strip at the scribe line, which is directly above the SDH.

B-464.4 Notch Indication. Position the search unit for the maximum opposite surface notch indication. Mark the number 8 on the indexing strip at the scribe line, which is directly above the notch.

B-464.5 Index Numbers. The numbers on the indexing strip indicate the position directly over the reflector in sixteenths of the V-path.

Figure B-464
Position Depth and Beam Path



B-464.6 Depth. The depth from the examination surface to the reflector is *T* at 8, $^3/_4T$ at 6 and 10, $^1/_2T$ at 4, $^1/_4T$ at 2, and 0 at 0. Interpolation is possible for smaller increments of depth. The position marks on the indexing strip may be corrected for the radius of the hole if the radius is considered significant to the accuracy of reflector's location.

B-465 CALIBRATION CORRECTION FOR PLANAR REFLECTORS PERPENDICULAR TO THE EXAMINATION SURFACE AT OR NEAR THE OPPOSITE SURFACE (SEE FIGURE B-465)

A 45 deg angle beam shear wave reflects well from a corner reflector. However, mode conversion and redirection of reflection occurs to part of the beam when a 60 deg angle beam shear wave hits the same reflector. This problem also exists to a lesser degree throughout the 50 deg to 70 deg angle beam shear wave range. Therefore, a correction is required in order to be equally critical of such an imperfection regardless of the examination beam angle.

B-465.1 Notch Indication. Position the search unit for maximum amplitude from the notch on the opposite surface. Mark the peak of the indication with an "X" on the screen.

B-465.2 45 deg vs. 60 deg. The opposite surface notch may give an indication 2 to 1 above DAC for a 45 deg shear wave, but only $^1/_2$ DAC for a 60 deg shear wave. Therefore, the indications from the notch shall be considered when evaluating reflectors at the opposite surface.

B-466 BEAM SPREAD (SEE FIGURE B-466)

Measurements of beam spread shall be made on the hemispherical bottom of round bottom holes (RBHs). The half maximum amplitude limit of the primary lobe of the beam shall be plotted by manipulating the search unit for measurements on reflections from the RBHs as follows.

B-466.1 Toward $^1/_4T$ Hole. Set the maximum indication from the $^1/_4T$ RBH at 80% of FSH. Move search unit toward the hole until the indication equals 40% of FSH. Mark the beam center line "toward" position on the block.

B-466.2 Away From $^1/_4T$ Hole. Repeat B-466.1, except move search unit away from the hole until the indication equals 40% of FSH. Mark the beam center line "away" position on the block.

Figure B-465
Planar Reflections

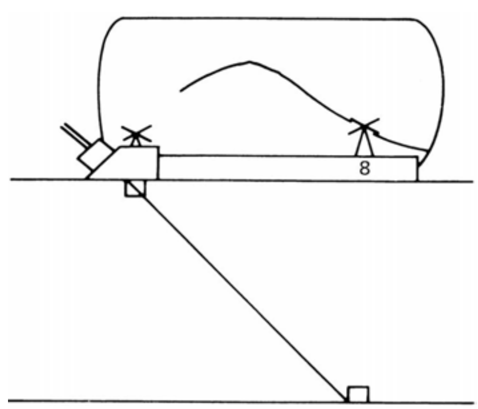
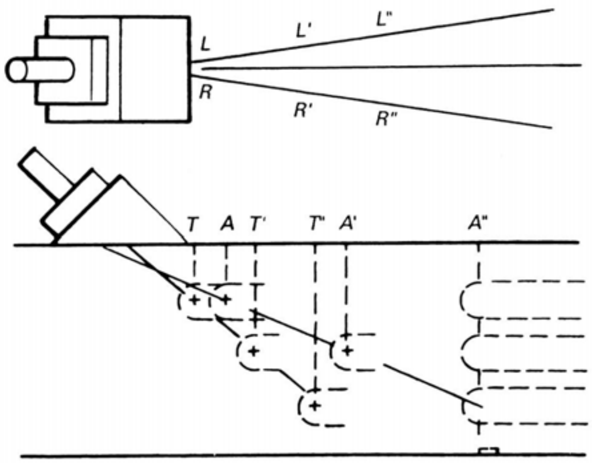


Figure B-466
Beam Spread



B-466.3 Right of $\frac{1}{4}T$ Hole. Reposition the search unit for the original 80% of FSH indication from the $\frac{1}{4}T$ RBH. Move the search unit to the right without pivoting the beam toward the reflector until the indication equals 40% of FSH. Mark the beam center line "right" position on the block.[16]

B-466.4 Left of $\frac{1}{4}T$ Hole. Repeat B-466.3, except move the search unit to the left without pivoting the beam toward the reflector until the indication equals 40% of FSH. Mark the beam center line "left" position on the block.[16]

B-466.5 $\frac{1}{2}T$ and $\frac{3}{4}T$ Holes. Repeat the steps in B-466.1 through B-466.4 for the $\frac{1}{2}T$ and $\frac{3}{4}T$ RBHs.

B-466.6 Record Dimensions. Record the dimensions from the "toward" to "away" positions and from the "right" to "left" positions marked on the block.

B-466.7 Perpendicular Indexing. The smallest of the three "toward" to "away" dimensions shall not be exceeded when indexing between scans perpendicular to the beam direction.

B-466.8 Parallel Indexing. The smallest of the three "right" to "left" dimensions shall not be exceeded when indexing between scans parallel to the beam direction.

B-466.9 Other Metal Paths. The projected beam spread angle determined by these measurements shall be used to determine limits as required at other metal paths.

NOTE: If laminar reflectors are present in the basic calibration block, the beam spread readings may be affected; if this is the case, beam spread measurements must be based on the best available readings.

NONMANDATORY APPENDIX C GENERAL TECHNIQUES FOR STRAIGHT BEAM CALIBRATIONS

C-410 SCOPE

This Appendix provides general techniques for straight beam calibration. Other techniques may be used.

C-460 CALIBRATION

C-461 SWEEP RANGE CALIBRATION[17] (SEE FIGURE C-461)

C-461.1 Delay Control Adjustment. Position the search unit for the maximum first indication from the $^1/_4T$ SDH. Adjust the left edge of this indication to line 2 on the screen with the delay control.

C-461.2 Range Control Adjustment. Position the search unit for the maximum indication from $^3/_4T$ SDH. Adjust the left edge of this indication to line 6 on the screen with the range control.

C-461.3 Repeat Adjustments. Repeat the delay and range control adjustments until the $^1/_4T$ and $^3/_4T$ SDH indications start at sweep lines 2 and 6.

C-461.4 Back Surface Indication. The back surface indication will appear near sweep line 8.

C-461.5 Sweep Readings. Two divisions on the sweep equal $^1/_4T$.

C-462 DISTANCE–AMPLITUDE CORRECTION (SEE FIGURE C-462)

The following is used for calibration from either the clad side or the unclad side:

(a) Position the search unit for the maximum indication from the SDH, which gives the highest indication.

(b) Adjust the sensitivity (gain) control to provide an 80% (±5%) of FSH indication. This is the primary reference level. Mark the peak of this indication on the screen.

(c) Position the search unit for maximum indication from another SDH.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum indication from the third SDH and mark the peak on the screen.

(f) Connect the screen marks for the SDHs and extend through the thickness to provide the distance–amplitude curve.

Figure C-461 Sweep Range

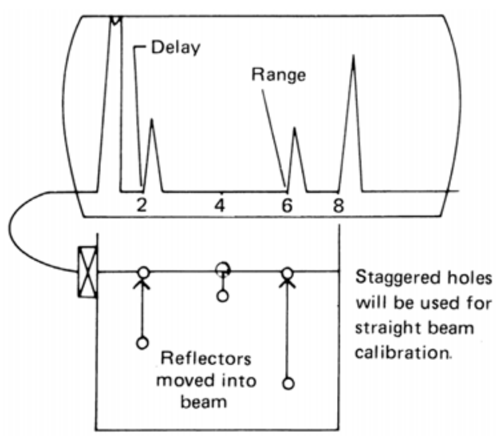
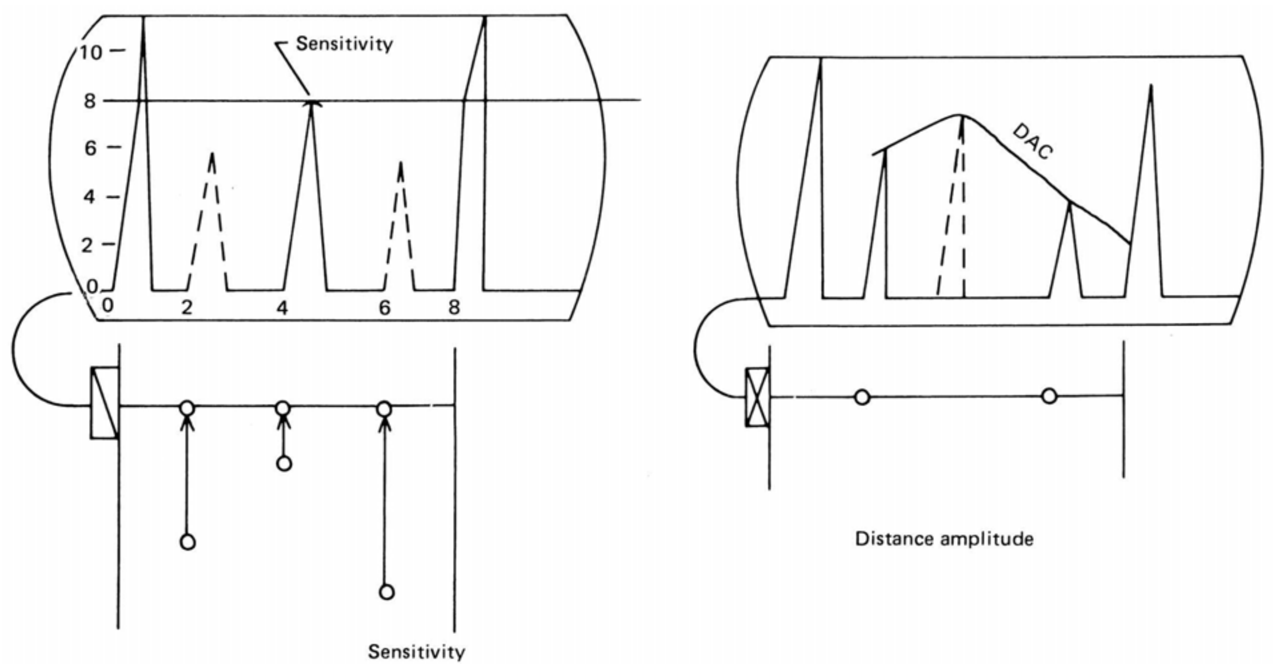


Figure C-462
Sensitivity and Distance–Amplitude Correction



NONMANDATORY APPENDIX D EXAMPLES OF RECORDING ANGLE BEAM EXAMINATION DATA

D-410 SCOPE

This Appendix provides examples of the data required to dimension reflectors found when scanning a weld and describes methods for recording angle beam examination data for planar and other reflectors. Examples are provided for when amplitude-based identification is required and dimensioning is to be performed for length only and for length and through-wall dimensions.

D-420 GENERAL

Referencing Code Sections provide several means of identifying reflectors based upon indication amplitude. These indications, in several Codes, must be interpreted as to their reflector's identity (i.e., slag, crack, incomplete fusion, etc.) and then evaluated against acceptance standards. In general, some percentage of the distance–amplitude correction (DAC) curve or reference level amplitude for a single calibration reflector is established at which all indications must be investigated as to their identity. In other cases, where the amplitude of the indication exceeds the DAC or the reference level, measurements of the indication's length may only be required. In other referencing Code Sections, measuring techniques are required to be qualified for not only determining the indication's length but also for its largest through-wall dimension.

D-470 EXAMINATION REQUIREMENTS

A sample of various Code requirements will be covered describing what should be recorded for various indications.

D-471 REFLECTORS WITH INDICATION AMPLITUDES GREATER THAN 20% OF DAC OR REFERENCE LEVEL

When the referencing Code Section requires the identification of all relevant reflector indications that produce indication responses greater than 20% of the DAC (20% DAC[18]) curve or reference level established in T-463 or T-464, a reflector producing a response above this level shall be identified (i.e., slag, crack, incomplete fusion, etc.).

D-472 REFLECTORS WITH INDICATION AMPLITUDES GREATER THAN THE DAC CURVE OR REFERENCE LEVEL

When the referencing Code Section requires the length measurement of all relevant reflector indications that produce indication responses greater than the DAC curve or reference level established in T-463 or T-464, indication length shall be measured perpendicular to the scanning direction between the points on its extremities where the amplitude equals the DAC curve or reference level.

D-473 FLAW SIZING TECHNIQUES TO BE QUALIFIED AND DEMONSTRATED

When flaw sizing is required by the referencing Code Section, flaw sizing techniques shall be qualified and demonstrated. When flaw sizing measurements are made with an amplitude technique, the levels or percentage of the DAC curve or reference level established in the procedure shall be used for all length and through-wall measurements.

D-490 DOCUMENTATION

Different Sections of the referencing Codes may have some differences in their requirements for ultrasonic examination. These differences are described below for the information that is to be documented and recorded for a particular reflector's indication. In illustrating these techniques of measuring the parameters of a reflector's indication responses, a simple method of recording the position of the search unit will be described.

Ultrasonic indications will be documented by the location and position of the search unit. A horizontal weld as shown in Figure D-490 has been assumed for the data shown in Table D-490. All indications are oriented with their long dimension parallel to the weld axis. The search unit's location, X, was measured from the 0 point on the weld axis to the centerline of the search unit's wedge. The search unit's position, Y, was measured from the weld axis to the sound beam's exit point of the wedge. Y is positive upward and negative downward. Search unit beam direction is usually 0 deg, 90 deg, 180 deg, or 270 deg.

Table D-490
Example Data Record

Weld No.	Ind. No.	Maximum DAC, %	Sound Path, in. (mm)	Loc. (X), in. (mm)	Pos. (Y), in. (mm)	Calibration Sheet	Beam Angle and Beam Direction, deg	Comments and Status
1541	1	45	1.7 (43.2)	4.3 (109.2)	−2.2 (−55.9)	005	45 (0)	Slag
1685	2	120	2.4 (61.0)	14.9 (378)	3.5 (88.9)	016	60 (180)	Slag
		100	2.3 (58.4)	15.4 (391)	3.6 (91.4)			Right end
		100	2.5 (63.5)	14.7 (373)	3.7 (94.0)			Left end
								Length = 15.4 in. − 14.7 in. = 0.7 in. (391 mm − 373 mm = 18 mm)
1967	3	120	4.5 (114.3)	42.3 (1 074)	−5.4 (−137.2)	054	45 (0)	Slag
		20	4.3 (109.2)	41.9 (1 064)	−5.2 (−132.1)			Minimum depth position
		20	4.4 (111.8)	41.6 (1 057)	−5.4 (−137.2)			Left end
		20	4.7 (119.4)	42.4 (1 077)	−5.6 (−142.2)			Maximum depth position
		20	4.6 (116.8)	42.5 (1 080)	−5.5 (−139.7)			Right end
								Length = 42.5 in. − 41.6 in. = 0.9 in. (1 080 mm − 1 057 mm = 23 mm)
								Through-wall dimension = (4.7 in. − 4.3 in.)(cos 45 deg) = 0.3 in. [(119.4 mm − 109.2 mm)(cos 45 deg) = 7.2 mm)]

GENERAL NOTE: Ind. No. = indication number; Loc. (X) = location along X axis; pos. (Y) = position (Y) from weld centerline; beam direction is toward 0, 90, 180, or 270 (see Figure D-490).

D-491 REFLECTORS WITH INDICATION AMPLITUDES GREATER THAN 20% OF DAC OR REFERENCE LEVEL

When the referencing Code Section requires the identification of all relevant reflector indications that produce reflector responses greater than 20% of the DAC curve or reference level, position the search unit to give the maximum amplitude from the reflector.

(a) Determine and record the maximum amplitude in percent of DAC or reference level.

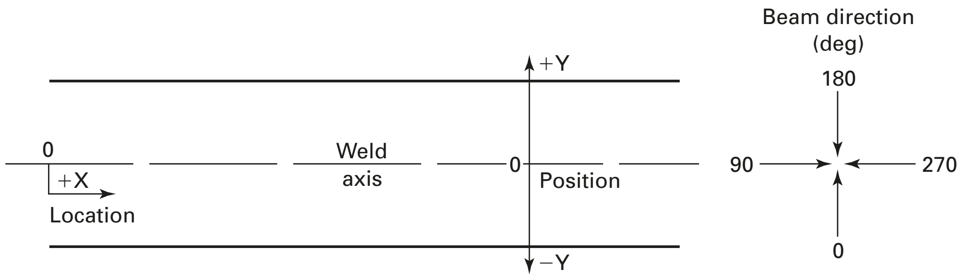
(b) Determine and record the sweep reading sound path to the reflector (at the left side of the indication on the sweep).

(c) Determine and record the search unit location (X) with respect to the 0 point.

(d) Determine and record the search unit position (Y) with respect to the weld axis.

(e) Record the search unit beam angle and beam direction.

Figure D-490
Search Unit Location, Position, and Beam Direction



A data record is shown in Table D-490 for an indication with a maximum amplitude of 45% of DAC as Weld 1541, Indication 1. From its characteristics, the reflector was determined to be slag.

D-492 REFLECTORS WITH INDICATION AMPLITUDES GREATER THAN THE DAC CURVE OR REFERENCE LEVEL

When the referencing Code Section requires a length measurement of all relevant reflector indications that produce indication responses greater than the DAC curve or reference level whose length is based on the DAC curve or reference level, do the recording in accordance with D-491 and the following additional measurements.

(a) First move the search unit parallel to the weld axis to the right of the maximum amplitude position until the indication amplitude drops to 100% DAC or the reference level.

(b) Determine and record the sound path to the reflector (at the left side of the indication on the sweep).

(c) Determine and record the search unit location (X) with respect to the 0 point.

(d) Determine and record the search unit position (Y) with respect to the weld axis.

(e) Next move the search unit parallel to the weld axis to the left passing the maximum amplitude position until the indication amplitude again drops to 100% DAC or the reference level.

(f) Determine and record the sound path to the reflector (at the left side of the indication on the sweep).

(g) Determine and record the search unit location (X) with respect to the 0 point.

(h) Determine and record the search unit position (Y) with respect to the weld axis.

(i) Record the search unit beam angle and beam direction.

A data record is shown in Table D-490 for an indication with a maximum amplitude of 120% of DAC as Weld 685, Indication 2, with the above data and the data required in D-491. From its characteristics, the reflector was determined to be slag and had an indication length of 0.7 in. If the indication dimensioning was done using SI units, the indication length is 18 mm.

D-493 REFLECTORS THAT REQUIRE MEASUREMENT TECHNIQUES TO BE QUALIFIED AND DEMONSTRATED

When the referencing Code Section requires that all relevant reflector indication length and through-wall dimensions be measured by a technique that is qualified and demonstrated to the requirements of that Code Section, the measurements of D-491 and D-492 are made with the additional measurements for the through-wall dimension as listed below. The measurements in this section are to be done at amplitudes that have been qualified for the length and through-wall measurement. A 20% DAC or 20% of the reference level has been assumed qualified for the purpose of this illustration instead of the 100% DAC or reference level used in D-492. Both length and through-wall determinations are illustrated at 20% DAC or the 20% of the reference level. The reflector is located in the first leg of the sound path (first half vee path).

(a) First move the search unit toward the reflector and scan the top of the reflector to determine the location and position where it is closest to the sound beam entry surface (minimum depth) and where the amplitude falls to 20% DAC or 20% of the reference level.

(b) Determine and record the sound path to the reflector (at the left side of the indication on the sweep).

(c) Determine and record the search unit location (X) with respect to the 0 point.

(d) Determine and record the search unit position (Y) with respect to the weld axis.

(e) Next move the search unit away from the reflector and scan the bottom of the reflector to determine the location and position where it is closest to the opposite surface (maximum depth) and where the amplitude falls to 20% DAC or 20% of the reference level.

(f) Determine and record the sound path to the reflector (at the left side of the indication on the sweep).

(g) Determine and record the search unit location (X) with respect to the 0 point.

(h) Determine and record the search unit position (Y) with respect to the weld axis.

(i) Record the search unit beam angle and beam direction.

A data record is shown in Table D-490 for an indication with a maximum amplitude of 120% of DAC as Weld 1967, Indication 3, with the above data and the data required in D-491 and D-492 for length at 20% DAC or 20% of the reference level. From its characteristics, the reflector was determined to be slag and the indication had a length of 0.9 in. If the dimensioning was done using SI units, the indication length is 23 mm and the through-wall dimension 7 mm.

NONMANDATORY APPENDIX E
COMPUTERIZED IMAGING TECHNIQUES

E-410 SCOPE

This Appendix provides requirements for computer imaging techniques.

E-420 GENERAL

Computerized imaging techniques (CITs) shall satisfy all of the basic instrument requirements described in T-431 and T-461. The search units used for CIT applications shall be characterized as specified in B-466. CITs shall be qualified in accordance with the requirements for flaw detection and/or sizing that are specified in the referencing Code Section.

The written procedure for CIT applications shall identify the specific test frequency and bandwidth to be utilized. In addition, such procedures shall define the signal processing techniques, shall include explicit guidelines for image interpretation, and shall identify the software code/program version to be used. This information shall also be included in the examination report. Each examination report shall document the specific scanning and imaging processes that were used so that these functions may be accurately repeated at a later time if necessary.

The computerized imaging process shall include a feature that generates a dimensional scale (in either two or three dimensions, as appropriate) to assist the operator in relating the imaged features to the actual, relevant dimensions of the component being examined. In addition, automated scaling factor indicators shall be integrally included to relate colors and/or image intensity to the relevant variable (i.e., signal amplitude, attenuation, etc.).

E-460 CALIBRATION

Calibration of computer imaging systems shall be conducted in such a manner that the gain levels are optimized for data acquisition and imaging purposes. The traditional DAC-based calibration process may also be required to establish specific scanning and/or flaw detection sensitivity levels.

For those CITs that employ signal processing to achieve image enhancement (SAFT-UT, L-SAFT, and broadband holography), at least one special lateral resolution and depth discrimination block for each specified examination shall be used in addition to the applicable calibration block required by Article 4. These blocks shall comply with J-431.

The block described in Figure E-460.1 provides an effective resolution range for 45 deg and 60 deg search units and metal paths up to about 4 in. (100 mm). This is adequate for piping and similar components, but longer path lengths are required for reactor pressure vessels. A thicker block with the same sizes of flat-bottom holes, spacings, depths, and tolerances is required for metal paths greater than 4 in. (100 mm), and a 4 in. (100 mm) minimum distance between the edge of the holes and the edge of the block is required. These blocks provide a means for determining lateral resolution and depth discrimination of an ultrasonic imaging system.

Lateral resolution is defined as the minimum spacing between holes that can be resolved by the system. The holes are spaced such that the maximum separation between adjacent edges of successive holes is 1.000 in. (25.40 mm). The spacing progressively decreases by a factor of two between successive pairs of holes, and the minimum spacing is 0.015 in. (0.38 mm). Depth discrimination is demonstrated by observing the displayed metal paths (or the depths) of the various holes. Because the hole faces are not parallel to the scanning surface, each hole displays a range [about 0.1 in. (2.5 mm)] of metal paths. The "A" row has the shortest average metal path, the "C" row has the longest average metal path, and the "B" holes vary in average metal path.

Additional blocks are required to verify lateral resolution and depth discrimination when 0 deg longitudinal-wave examination is performed. Metal path lengths of 2 in. and 8 in. (50 mm and 200 mm), as appropriate, shall be provided as shown in Figure E-460.2 for section thicknesses to 4 in. (100 mm), and a similar block with 8 in. (200 mm) metal paths is needed for section thicknesses over 4 in. (100 mm).

E-470 EXAMINATION

E-471 SYNTHETIC APERTURE FOCUSING TECHNIQUE FOR ULTRASONIC TESTING (SAFT-UT)

The Synthetic Aperture Focusing Technique (SAFT) refers to a process in which the focal properties of a large-aperture focused search unit are synthetically generated from data collected while scanning over a large area using a small search unit with a divergent sound beam. The processing required to focus this collection of data is a three-dimensional process called beam-forming, coherent summation, or synthetic aperture processing. The SAFT-UT process offers an inherent advantage over physical focusing processes because the resulting image is a full-volume, focused characterization of the material volume being examined. Traditional physical focusing processes provide focused data over only the depth of the focus zone of the transducer.

For the typical pulse-echo data collection scheme used with SAFT-UT, a focused search unit is positioned with the focal point located at the surface of the material under examination. This configuration produces a divergent ultrasonic beam in the material. Alternatively, a small-diameter contact search unit may be used to generate a divergent beam. As the search unit is scanned over the surface of the material, the A-scan record (RF waveform) is digitized for each position of the search unit. Any reflector present produces a collection of echoes in the A-scan records. For an elementary single-point reflector, the collection of echoes will form a hyperbolic surface within the data-set volume. The shape of the hyperboloid is determined by the depth of the reflector and the velocity of sound in the material. The relationship between echo location in the series of A-scans and the actual location of reflectors within the material makes it possible to reconstruct a high-resolution image that has a high signal-to-noise ratio. Two separate SAFT-UT configurations are possible:

(a) the single-transducer, pulse-echo configuration; and

(b) the dual-transducer, tandem configuration (TSAFT).

In general, the detected flaws may be categorized as volumetric, planar, or cracks. Flaw sizing is normally performed by measuring the vertical extent (cracks) or the cross-sectional distance (volumetric/planar) at the −6 dB levels once the flaw has been isolated and the image normalized to the maximum value of the flaw. Multiple images are often required to adequately categorize (classify) the flaw and to characterize the actual flaw shape and size. Tandem sizing and analysis uses similar techniques to pulse-echo, but provides images that may be easier to interpret.

The location of indications within the image space is influenced by material thickness, velocity, and refracted angle of the UT beam. The SAFT algorithm assumes isotropic and homogeneous material; i.e., the SAFT algorithm requires (for optimum performance) that the acoustic velocity be accurately known and constant throughout the material volume.

Lateral resolution is the ability of the SAFT-UT system to distinguish between two objects in an x-y plane that is perpendicular to the axis of the sound beam. Lateral resolution is measured by determining the minimum spacing between pairs of holes that are clearly separated in the image. A pair of holes is considered separated if the signal amplitude in the image decreases by at least 6 dB between the peak signals of two holes.

Depth resolution is the ability of a SAFT-UT system to distinguish between the depth of two holes whose axes are parallel to the major axis of the sound beam. Depth resolution is measured by determining the minimum difference in depth between two holes.

The lateral resolution for a SAFT-UT system is typically 1.5 wavelengths (or better) for examination of wrought ferritic components, and 2.0 wavelengths (or better) for examination of wrought stainless steel components. The depth resolution for these same materials will typically be 0.25 wavelengths (or better).

E-472 LINE-SYNTHETIC APERTURE FOCUSING TECHNIQUE (L-SAFT)

The Line Synthetic Aperture Focusing Technique (L-SAFT) is useful for analyzing detected indications. L-SAFT is a two-dimensional process in which the focal properties of a large-aperture, linearly focused search unit are synthetically generated from data collected over a scan line using a small search unit with a diverging sound beam. The processing required to impose a focusing effect of the acquired data is also called synthetic aperture processing. The L-SAFT system can be operated like conventional UT equipment for data recording. It will function with either single- or dual-element transducers.

Analysis measurements, in general, are performed to determine flaw size, volume, location, and configuration. To decide if the flaw is a crack or volumetric, the crack-tip-diffraction response offers one criterion, and the superimposed image of two measurements made using different directions of incidence offers another.

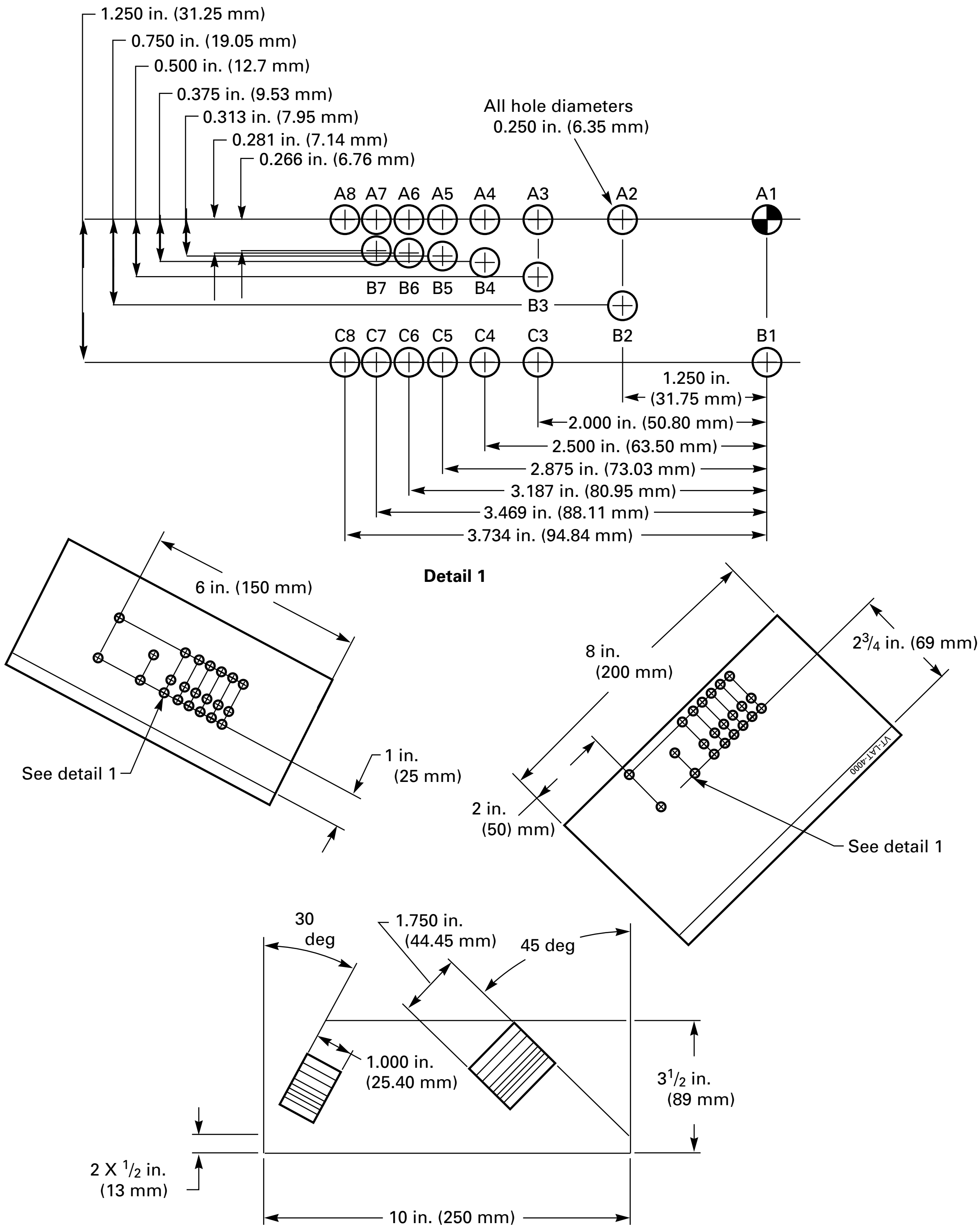
All constraints for SAFT-UT apply to L-SAFT and vice versa. The difference between L-SAFT and SAFT-UT is that SAFT-UT provides a higher resolution image than can be obtained with L-SAFT.

E-473 BROADBAND HOLOGRAPHY TECHNIQUE

The holography technique produces an object image by calculation based on data from a diffraction pattern. If the result is a two-dimensional image and the data are acquired along one scan, the process is called "line-holography." If the result is a two-dimensional image based upon an area scanned, then it is called "holography." For the special case of applying holography principles to ultrasonic testing, the image of flaws (in more than one dimension) can be obtained by recording the amplitude, phase, and time-of-flight data from the scanned volume. The holography process offers a unique feature because the resulting image is a one- or two-dimensional characterization of the material.

This technique provides good resolution in the axial direction by using broadband search units. These search units transmit a very short pulse, and therefore the axial

Figure E-460.1
Lateral Resolution and Depth Discrimination Block for 45 deg and 60 deg Applications



GENERAL NOTES:
(a) View rotated for clarity.
(b) Insonification surface is shown at bottom.
(c) Tolerances: decimals: 0.XX = ±0.03; 0.XXX = ±0.005; angular: ±1 deg.

Figure E-460.1
Lateral Resolution and Depth Discrimination Block for 45 deg and 60 deg Applications (Cont'd)

GENERAL NOTES (CONT'D):
(d) Hole identification:
  (1) Engrave or stamp as shown with the characters upright when the large face of the block is up.
  (2) Nominal character height is 0.25 in. (6 mm).
  (3) Start numbering at the widest-spaced side.
  (4) Label row of eight holes A1–A8.
  (5) Label diagonal set of seven holes B1–B7.
  (6) Label remaining six holes C3–C8.
(e) Hole spacing: minimum 0.010 in. (0.25 mm) material between hole edges.
(f) Hole depths: 30 deg face: 1.000 in. (25.40 mm); 45 deg face: 1.750 in. (44.45 mm).
(g) Drawing presentation: holes are shown from drilled face of block.
(h) Hole ends to be flat and parallel to drilled surface within 0.001 in. (0.03 mm) across face of hole.
(i) Maximum radius between side and face of hole is 0.005 in. (0.13 mm).

resolution is improved. The maximum bandwidth may be 20 MHz without using filtering, and up to 8 MHz using an integrated filter.

Analysis measurements, in general, are performed to obtain information on size, volume, location, and configuration of detected flaws. The results of the holography-measurements per scan line show a two-dimensional image of the flaw by color-coded display. The size of flaws can be determined by using the 6 dB drop in the color code. More information on the flaw dimensions is obtained by scans in different directions (i.e., parallel, perpendicular) at different angles of incidence. To decide if the flaw is a crack or a volumetric flaw, the crack tip technique offers one criterion and comparison of two measurements from different directions of incidence offers another. Measurement results obtained by imaging techniques always require specific interpretation. Small variations in material thickness, sound velocity, or refracted beam angle may influence the reconstruction results. The holography processing calculations also assume that the velocity is accurately known and constant throughout the material.

E-474 UT-PHASED ARRAY TECHNIQUE

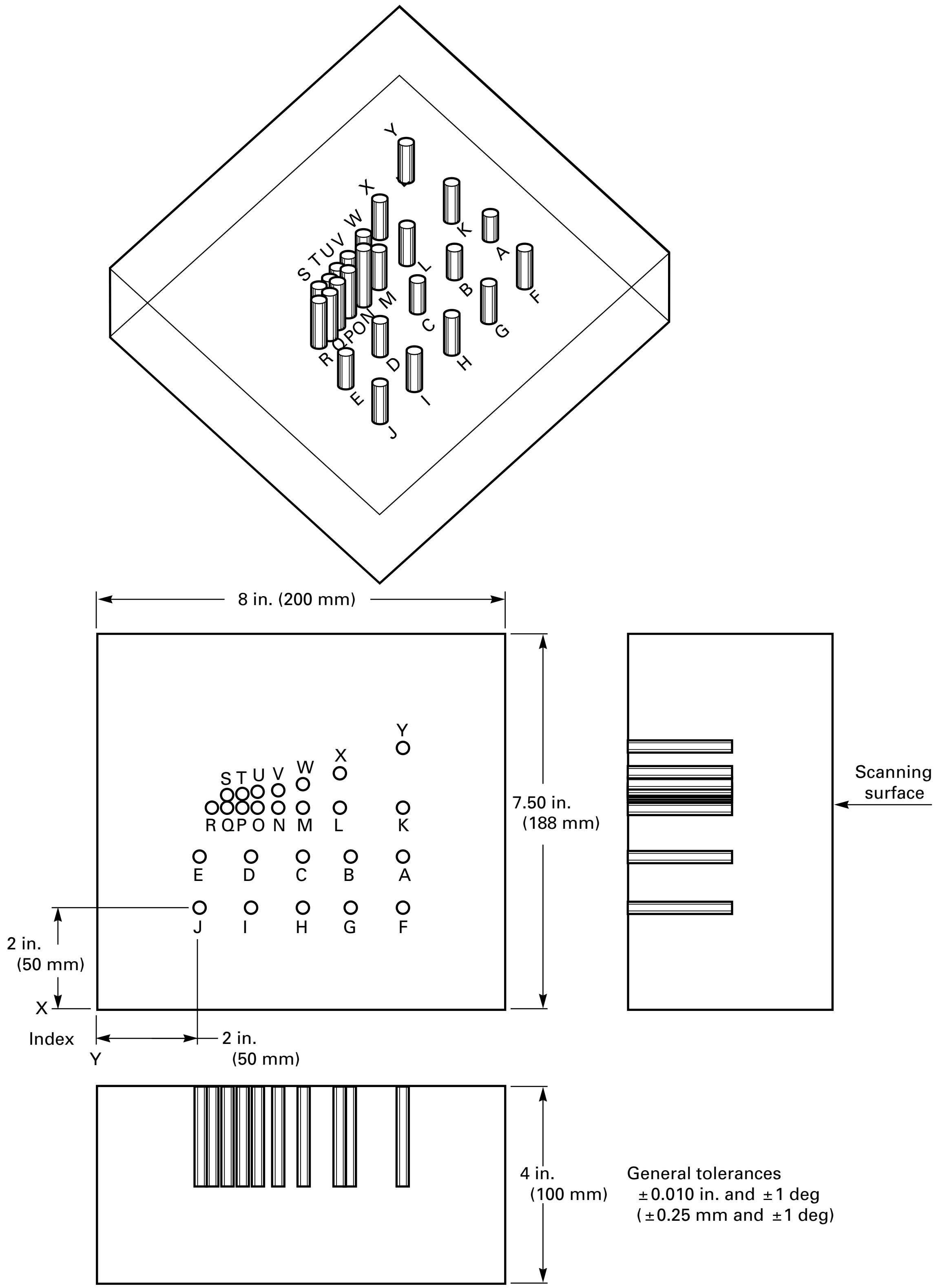
The UT-Phased Array Technique is a process wherein UT data are generated by controlled incremental variation of the ultrasonic beam angle in the azimuthal or lateral direction while scanning the object under examination. This process offers an advantage over processes using conventional search units with fixed beam angles because it acquires considerably more information about the reflecting object by using more aspect angles in direct impingement.

Each phased array search unit consists of a series of individually wired transducer elements on a wedge that are activated separately using a pre-selectable time delay pattern. With a linear delay time between the transmitter pulses, an inclined sound field is generated. Varying the angle of refraction requires a variation of the linear distribution of the delay time. Depending on the search unit design, it is possible to electronically vary either the angle of incidence or the lateral/skew angle. In the receiving mode, acoustic energy is received by the elements and the signals undergo a summation process utilizing the same time delay pattern as was used during transmission.

Flaw sizing is normally performed by measuring the vertical extent (in the case of cracks) or the cross-sectional distance (in the case of volumetric/planar flaws) at the 6 dB levels once the flaw has been isolated and the image normalized. Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that are easier to interpret since specular reflection is used for defects oriented perpendicular to the surface. For cracks and planar defects, the result should be verified using crack-tip-diffraction signals from the upper and lower ends of the flaw, since the phased array approach with tomographic reconstruction is most sensitive to flaw tip indications and is able to give a clear reconstruction image of these refraction phenomena. As with other techniques, the phased array process assumes isotropic and homogeneous material whose acoustic velocity is constant and accurately known.

Sectorial scans (S-scans) with phased array provides a fan-like series of beam angles from a single emission point that can cover part or all of a weld, depending on search unit size, joint geometry, and section thickness. Such a series of beam angles can demonstrate good detectability of side-drilled holes because they are omnidirectional reflectors. This is not necessarily the case for planar reflectors (e.g., lack of fusion and cracks) when utilizing line scanning techniques where the beam could be misoriented to the point they cannot be detected. This is particularly true for thicker sections when using single line scanning techniques.

Figure E-460.2
Lateral and Depth Resolution Block for 0 deg Applications



E-475 UT-AMPLITUDE TIME-OF-FLIGHT LOCUS-CURVE ANALYSIS TECHNIQUE

The UT-amplitude time-of-flight locus-curve analysis technique utilizes multiple search units in pulse-echo, transmitter-receiver, or tandem configuration. Individually selectable parameters control the compression of the A-scan information using a pattern-recognition algorithm, so that only the relevant A-scan amplitudes are stored and further processed.

The parameter values in the A-scan compression algorithm determine how many pre-cursing and how many post-cursing half-wave peaks must be smaller than a specific amplitude, so that this largest amplitude is identified as as relevant signal. These raw data can be displayed in B-, C-, and D-scan (side, top, and end view) presentations, with selectable color-code increments for amplitude and fast zoom capabilities. This operating mode is most suitable for detection purposes. For discrimination, a two-dimensional spatial-filtering algorithm is applied to search for correlation of the time-of-flight raw data with reflector-typical time-of-flight trajectories.

Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that may be easier to interpret since the specular reflections from flaws oriented perpendicular to the surface are used. For cracks and planar flaws, the results should be verified with crack-tip-diffraction signals from the upper and lower end of the flaw since the acoustic parameters are very sensitive to flaw tip indications and a clear reconstruction image of these refraction phenomena is possible with this technique.

The location of indications within the image space is influenced by material thickness and actual sound velocity (i.e., isotropic and homogeneous material is assumed). However, deteriorating influences from anisotropic material (such as cladding) can be reduced by appropriate selection of the search unit parameters.

E-476 AUTOMATED DATA ACQUISITION AND IMAGING TECHNIQUE

Automated data acquisition and imaging is a multichannel technique that may be used for acquisition and analysis of UT data for both contact and immersion applications. This technique allows interfacing between the calibration, acquisition, and analysis modes; and for assignment of specific examination configurations. This technique utilizes a real-time display for monitoring the quality of data being collected, and provides for display of specific amplitude ranges and the capability to analyze peak data through target motion filtering. A cursor function allows scanning the RF data one waveform at a time to aid in crack sizing using tip-diffraction. For both peak and RF data, the technique can collect, display, and analyze data for scanning in either the axial or circumferential directions.

This technique facilitates detection and sizing of both volumetric and planar flaws. For sizing volumetric flaws, amplitude-based methods may be used; and for sizing planar flaws, the crack-tip-diffraction method may be used. An overlay feature allows the analyst to generate a composite image using several sets of ultrasonic data. All data displayed in the analyze mode may be displayed with respect to the physical coordinates of the component.

(19)

NONMANDATORY APPENDIX F EXAMINATION OF WELDS USING FULL MATRIX CAPTURE

F-410 SCOPE

This Appendix contains a description of the processes and technique(s) for the full matrix capture (FMC) ultrasonic (UT) examination technique. An FMC examination consists of data collection and image construction aspects.

F-420 GENERAL

A full matrix of time domain signals from transmitting patterns and receiving elements, within a given array, is captured electronically. This is the creation of the data set.

The data set is then used to reconstruct an image through post-processing techniques. Reconstruction may be done in real time or at any time after acquisition. There are many image reconstruction techniques consisting of processing algorithms, and different techniques may be applied to the same data set.

It is important to note that the data collection in FMC is not necessarily contingent in any way on subsequent processing to form an image; however, the image reconstruction is potentially constrained by the data obtained in the FMC process. There is not necessarily a need to compute any setting prior to or during the FMC process, except the time of flight (TOF) and dynamic range of the signal acquired. For some of the cases, no prior information need be applied nor assumed to collect data. However, to reconstruct a useful image, the examiner must ensure that all the information for processing is contained within the FMC.

F-421 POST-PROCESSING

For simplicity, the elementary total focusing method (TFM) is used in this Appendix as an example. Other signal-processing techniques are also viable.

The elementary TFM is a common method of image reconstruction in which the value of each constituent datum of the image results from focused ultrasound. TFM may also be understood as a broad term encompassing a family of processing techniques for image reconstruction. It is possible that equipment of different manufacture may legitimately generate very different TFM images using the same FMC data, with no image being necessarily more valid than another. Other signal-processing techniques may be considered variants or derivatives of TFM if they satisfy the broad definition of TFM above. Contrary to the name, other TFM variants intentionally defocus to achieve the desired results.

A TFM examination may be reconstructed from non-FMC data. However, this Appendix only addresses images reconstructed from FMC data.

F-430 EQUIPMENT

F-432 SEARCH UNIT SELECTION

FMC/TFM examinations have a potential advantage of better image resolution (the ability to distinguish two separate reflectors that are in close proximity) over other UT techniques. FMC/TFM is potentially also less sensitive to the shape or orientation of the reflector than other UT techniques. Since it is a UT technique, FMC/TFM examination is governed by the same laws of physics that apply to any UT technique [e.g., conventional UT, phased-array UT testing (PAUT), and TOF diffraction (TOFD)]. A search unit design matching the application is one of the most important factors to realize the potential benefits and advantages of these techniques. Any given array's performance is also relevant to the examination area or required examination volume.

In general, the smaller the element(s) and element pitch, combined with a high element count, the larger the optimized examination area will be, including a greater depth of field, and less dependent on the orientation of the reflector. This is true for any UT technique. Any given array search unit that performs poorly with PAUT will probably perform poorly with FMC/TFM, diminishing the potential for superior imaging. For example, although it is possible to examine a thick component using a small number of elements (e.g., a 16-element array), the examiner should not expect significant resolution benefits over a larger array.

(a) The examiner may take the following into consideration for search unit selection:

(1) The aperture should be long enough to produce a far enough near field (size is normalized with the wavelength).

(2) An indication that is farther away in time will have less resolution, and a larger array may be desirable for achieving better results.

(3) Decreasing the wavelength will improve resolution and is typically accomplished by increasing the frequency of the array. Material velocity also has an impact on wavelength in that an increase in velocity will increase the wavelength.

(4) Element pitch is important; each grid datum is calculated with proper information from the signal. When combined with the aperture length, this means that the number of elements is an important parameter. It is important to realize that the pitch of the array is not directly correlated to the image grid spacing as it is in PAUT.

(b) The configuration of the search unit will also influence the image reconstruction process, which is related to how the frames are collected. To improve image processing, the examiner should consider the following:

(1) An array with a small pitch will generally perform better (size is normalized with the wavelength).

(2) An array with a small element size will perform better, to the point where being too small affects the sensitivity.

(3) The examination volume should be within the range where the search unit arrangement naturally performs best for the material (e.g., the range is within acceptable elementary beam divergence and attenuation).

F-440 MISCELLANEOUS

F-441 FULL MATRIX CAPTURE

FMC refers to the general technique of acquiring several to all signal combinations from several to all elements within an aperture (whether it be virtual or real). The FMC data are strictly dependent on time. The general case for a linear array is that the FMC is composed by an index of the receiving pattern and another index by a transmit pattern, where each cell of the FMC is an A-scan. Some variations include different waveforms other than cylindrical waves issued from each element; therefore, the matrix might have more than three dimensions (e.g., transmitter index, receiver index, A-scan). The most elementary subset of the FMC method consists of acquiring information from all receiving elements in parallel for each element in transmission as described in Table F-441-1.

F-442 TOTAL FOCUSING METHOD

The TFM has simpler user settings and is capable of better resolution or depth of field over a larger region than if the search unit is properly designed for the examination. By using variations of the mathematical processes used for TFM, it is possible to gain advantages such as improved image resolution and less scattering of sound waves from material structure noise. TFM processing can be performed either in real time inside the equipment during the acquisition or during post-processing by other means. It is possible to apply TFM processing on FMC data that was previously acquired, stored in files, or archived.

F-442.1 Basic Concept of the TFM Family. TFM, using the search unit, coupling, and material information, can convert FMC data into an image representative of the part being examined, relative to its dimension. When processing FMC data, each point within the grid is calculated for the given array.

The general TFM method consists of calculating the amplitude value, whose generating function depends on the specific variant of TFM being applied, for each data point within the grid. The name "total focusing method" originated from the fact that each point calculated in the grid is intended to be perfectly focused.

As is the case with FMC, TFM is inclusive of an entire family of processes. A comparison of the generic methods of focusing for conventional PAUT and for actively focused FMC/TFM, which all generate a merged or composite image (grid), and whose name depends on the technique, is illustrated in Figures F-451.1-1 and F-451.1-2.

F-450 TECHNIQUES

F-451 CONVENTIONAL PHASED-ARRAY VS. FMC/TFM

The conventional PAUT technique consists of beam forming with an aperture (virtual search unit) in real time, using delay laws for both the transmit and receive sides. The raw data generated by each element of the array is processed (via beam forming) within the

Table F-441-1
An Illustrated Elementary Transmit/Receive Matrix

Receiving Elements	Transmitting Elements 1	2	3	*N* − 1	*N*
1	Ascan_1_1	Ascan_2_1	Ascan_3_1	Ascan_*N*−1_1	Ascan_*N*_1
2	Ascan_1_2	Ascan_2_2	Ascan_3_2	Ascan_*N*−1_2	Ascan_*N*_2
3	Ascan_1_3	Ascan_2_3	Ascan_3_3	Ascan_*N*−1_3	Ascan_*N*_3
N − 1	Ascan_1_*N*−1	Ascan_2_*N*−2	Ascan_3_*N*−1	Ascan_*N*−1_*N*−1	Ascan_*N*−1_*N*
N	Ascan_2_*N*	Ascan_2_*N*	Ascan_3_*N*	Ascan_*N*−1_*N*	Ascan_*N*_*N*

instrument, creating A-scan information in real time and generating image(s) that are essentially stacked A-scans, as opposed to FMC/TFM, which is non-beam-forming.

F-451.1 Typical Workflow Process. Figures F-451.1-1 through F-451.1-4 illustrate the typical workflow processes mentioned in F-450 and illustrate that for PAUT the following is true:

(a) The delay law calculation is determined by the type of image reconstruction (sector scan, linear scan, etc.) and other parameters such as travel time to the focus point.

(b) The data acquisition method can be determined by the type of focusing [typically the case of dynamic depth focusing (DDF), zone focusing, linear scan, or sectorial scan].

(c) The active focusing necessitates that the focal laws be generated prior to acquisition.

F-451.2 Advantages of TFM (Synthetic Focusing). The following are some of the advantages of TFM:

(a) Only one FMC data acquisition is enough to generate the various images, even when the equipment processed a different path/mode during acquisition or the FMC data was stored such that the TFM processing software could reconstruct several paths/modes. Instead of only for that path(s)/modes(s), it is possible to apply various TFM processes to stored FMC as well.

(b) An accurate model of the component can be generated with FMC data, which improves the resolution, and is a function of the array and wedge definition and of the position of the grid. In addition, the ability to resolve component and weld geometry in the reconstructed image has advantages (e.g., verification of equipment setup and less ambiguous interpretation).

(c) The setting(s) (e.g., focal law calculations) can be completely disassociated from the acquisition. In the case of elementary FMC/TFM, the only relations are the array pitch, velocities, and, when the TFM process is not adaptive, the relative geometry of the search unit with the part.

(d) Complex or high-performance TFM methods offer greater flexibility to correct for the lack of knowledge of the inspected part and its characteristics, enhance the resolution, improve profiling of the indication, reduce material structural noise, etc.

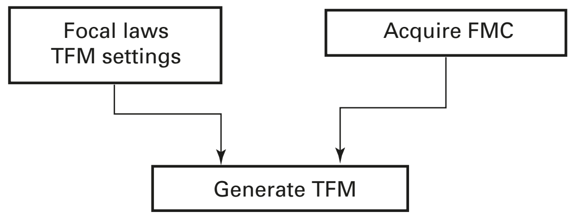
TFM is the result of the computation from data that was acquired independently. It brings possibilities such as using different processing, with the same FMC data, at the same time or in post processing, using different algorithm(s). This may be advantageous for a particular examination scenario.

F-460 CALIBRATION

F-461 AMPLITUDE FIDELITY

In simple terms, amplitude fidelity is the digital preservation of the signal amplitude information. The difference is a variation in sensitivity. The issue can either be that the amplitude varies too much because of the range of the grid size or by having too coarse a grid resolution regarding the lateral resolution of the system. There are several factors that influence the outcome, and an inadequate setup for a given component can lead to poor examination results.

Figure F-451.1-1
FMC/TFM Generic Workflow



Some of the parameters that can affect amplitude fidelity are physical properties, such as component material, search unit characteristics, wedge definition, and the position of the grid relative to them. Other parameters that may affect amplitude fidelity are FMC instrument settings (e.g., the sampling frequency, range, and dynamic setting) and settings and particularities of the TFM processes used by the equipment. The definition of the grid is essential for this check and therefore for the examination.

There are many ways to check or calculate amplitude fidelity for a given setup. The following is one example using a side-drilled hole (SDH) in proximity to the surface, yet past the dead zone, with an additional SDH placed 0.2 in. (5 mm) from the back wall, by observing the amplitude response while moving the search unit to cover the whole grid from each extremity of the search unit across the SDHs. Scanning across the SDHs should be done with an encoder employing a micro-adjustment, such as 0.004 in. (0.1 mm). If the SDHs are separated by 0.2 in. (5 mm) or less, due to thickness, then one hole is adequate. When using two holes, it is necessary to space them enough laterally to avoid the response from one influencing the other.

This example consists of moving the search unit along the test piece laterally such that the grid to be used during the examination(s) scans the SDHs and displays each along the lateral axis. The amplitude of the signal can be observed and measured for each position of the grid relative to the SDHs.

The amplitude fidelity is the measurement in variation of the maximum amplitude response of each SDH between the consecutive points of the grid, for the entire grid, as the SDH crosses along its lateral axis.

Figure F-451.1-2
Active Focusing Workflow

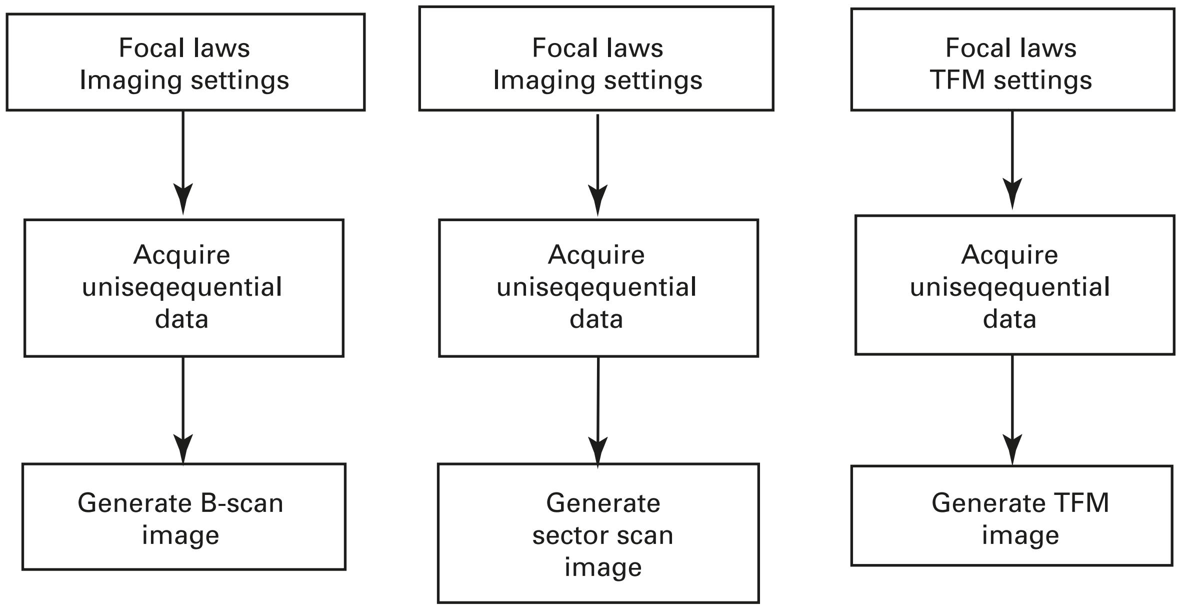


Figure F-451.1-3
Active Focusing Workflow With FMC Data Acquisition

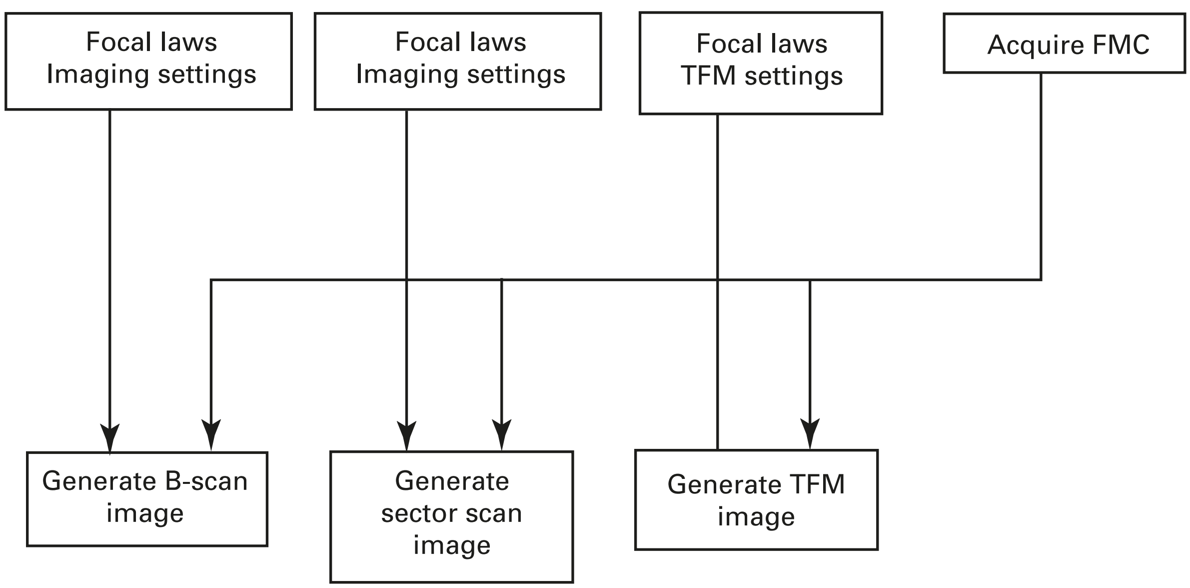
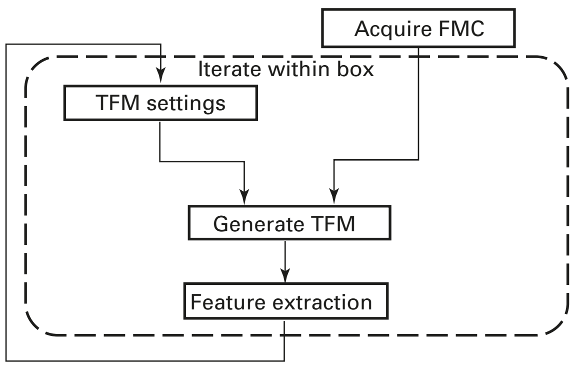


Figure F-451.1-4
Example of an Iterative FMC/TFM Workflow as an Adaptation of That Shown in Figure F-451.1-1



GENERAL NOTE: Iterative FMC/TFM can be used for some cases of adaptive TFM or for feature extraction (e.g., to enhance the resolution or reduce the material structure noise).

NOTE: The examiner needs to ensure the grid has a resolution that is fine enough to guarantee amplitude fidelity and that will meet the requirement of Article 4, Mandatory Appendix XI, XI-461. For example, in an extreme case having too coarse a grid, the examiner may simply not detect a small reflector. When a large high-frequency array is used, the lateral resolution can be much finer than expected in a smaller lower-frequency or out-of-focus array. The same situation can occur with a search unit having an inadequate definition or, in some cases, a mismatch between the wedge and array definition, especially regarding the position of the grid relative to them.

The amplitude fidelity check shall be performed for each path/mode that will be used during the inspection, and the instrument UT and mechanical setting(s) shall be the same as those used for the examination.

F-470 EXAMINATION

F-471 ULTRASONIC PATHS/MODES

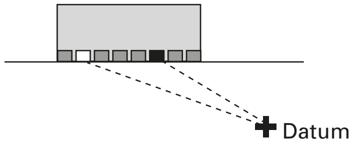
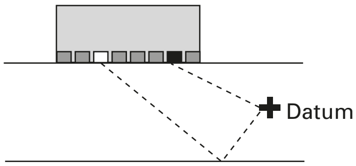
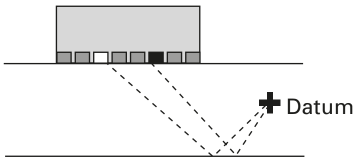
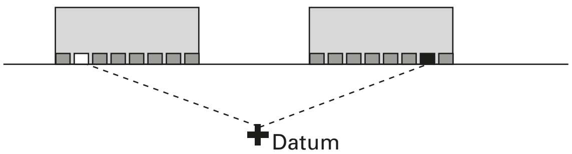
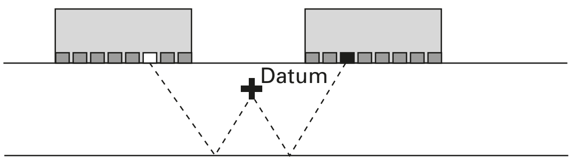
To make the imaging possible for defects detected through a multiplicity of possible modes (including tip diffraction, reflection, corner echoes, and mode conversion), the TFM algorithm has been generalized in the following way.

NOTE: In the case of TFM, the word "mode" is preferred to "path" because in conventional UT, whether it is PAUT or not, the term "path" correctly conveys the way the wave interaction occurs within the material (multiple paths occur within the same mode), whether there is reflection or not, implicitly considering the wave propagation within a beam, and therefore the notion of ray-tracing is also correct. In the case of TFM, each datum is calculated and is not the result of beam interaction within the material. Therefore, the notion of ray-tracing does not apply for the datum itself, but only for the individual sound waves between the transmit and receive patterns.

Table F-471-1 and Figure F-471-1 provide examples of different possible path(s)/mode(s), but the paths/modes shown should not be considered a complete list, as the Figures could be extended with additional variables.

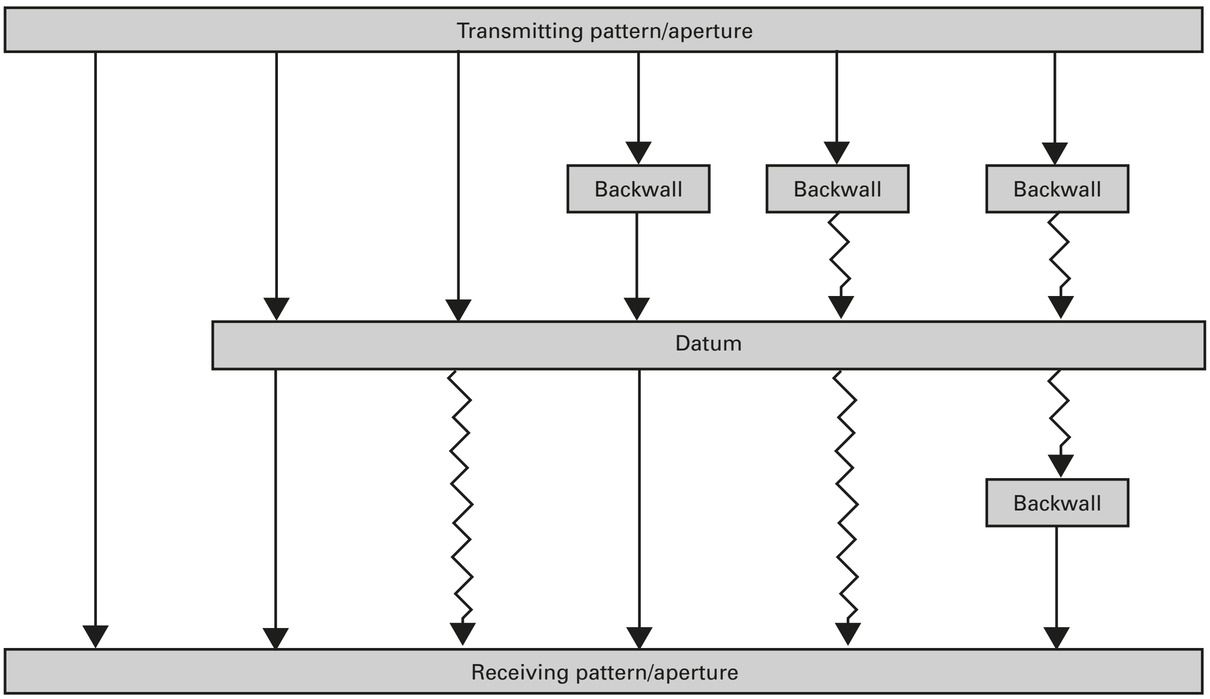
Denoted here by "modes," the different types of possible UT sound paths include "direct paths" L–L, L–T, T–L, and T-T and "corner paths" L–LL, T–TT, and L–TT, where "L" stands for longitudinal wave and "T" for transverse (shear wave). The same basic nomenclature can be applied for every possible path/mode. The examiner can therefore obtain, by TFM, one image corresponding to a mode by simply replacing in the computational step in the TFM TOF calculation(s) with suitable calculations corresponding to a specific mode or modes. The different paths or modes can be TFM processed from the same FMC data only if the A-scan range of each cell of the FMC is sufficient to contribute to the calculation. The TFM multipath/multimode is then possible within only one FMC acquisition, either in post-processing or in real time if the equipment offers this feature.

Table F-471-1
Ultrasonic Imaging Paths/Modes

Illustrated Example of an Imaging Path [Note (1)]	Mode [Note (2)]
	Direct transmit, direct receive: T–T, L–L
	Direct transmit, indirect receive or indirect transmit, direct receive: T–TT, TT–T, LL–L, L–LL, LT–T, T–TL, TT–L, L–TT
	Indirect transmit, indirect receive: TT–TT, LL–LL, TL–LT
	Direct transmit, direct receive: L–L, T–T
	Indirect transmit, indirect receive: TT–TT, LL–LL, TL–LT

NOTES:
(1) Each sketch is representative of a specific path of a mode.
(2) This is not an exhaustive list of modes.

Figure F-471-1
Examples of Ultrasonic Imaging Modes



GENERAL NOTES:
(a) This Figure shows some of the different modes that are available. L indicates longitudinal wave and T indicates transverse (shear wave). Illustrated are some examples of different modes with pulse echo FMC, and pitch-catch, including transmit receive longitudinal (TRL), using separate probes for pulsing and receiving.
(b) Two capital letters placed together (e.g., L–L) represent a path/mode that reflects from a datum. A dash incorporated into this nomenclature (e.g., LL–L) indicates the returning sound to the search unit.
(c) Other means of identifying the path/modes occur in industry. For example, letters may denote a change in sound direction. In this case, "LL–L" would be "LrbLdL," where "rb" indicates "rebound" (from back wall, etc.), and "d" indicates a datum.

NOTES:
(1) L = longitudinal wave cross talk; no interaction with the datum (image point).
(2) L–L = direct: longitudinal wave directly to the datum and longitudinal wave directly from the datum.
(3) L–T = direct: longitudinal wave directly to the datum and transverse wave directly from the datum.
(4) LL–L = half-skip: longitudinal wave reflecting from back wall without mode conversion on its way to the datum and longitudinal wave directly from the datum.
(5) LT–T = half-skip: longitudinal wave reflecting from back wall with mode conversion on its way to the datum and transverse wave directly from the datum.
(6) LT–TL = full-skip: longitudinal wave reflecting from back wall with mode conversion on its way to the datum and transverse wave reflecting from back wall with mode conversion on its way from the datum.

F-472 SELECTION OF THE PATH(S)/MODE(S)

Since FMC can be considered common to all modes, selection of the path(s)/mode(s) can be done during analysis if the FMC data has been recorded. If this is not preferable for any reason, it is necessary to make the selection prior to acquisition.

Selection of the modes can follow the same criteria as in conventional UT or PAUT. It is important to remember that although they are commonly drawn or depicted in this manner, the method for creating the FMC data set is completely different and has nothing to do with ray-tracing. Similarities include the following:

(a) Shear waves provide a short wavelength for a smaller resolution and better sensitivity to planar flaws, but the penetration is questionable for some materials. However, shear wave generation must be present in the FMC process.

NOTE: An aperture placed on a component with an orientation toward the reflector that does not agree with the physics of shear generation or, for example, without significant refraction presents a risk of generating so few shear waves that the reconstruction would still be impossible by TFM despite the power of such processing.

(b) Indirect mode(s) (e.g., LL–L, TT–T) and conversion mode(s) (e.g., LT–L) allow the ability to follow the profile of a vertically oriented indication, while direct modes (e.g., L–L, T–T) or reflection modes (e.g., LL–LL, TT–TT) provide more sensitivity and precision to the tip(s) of the indication from other flaw orientations.

F-473 DEFECT ORIENTATION AND SENSITIVITY

Assuming the probe and wedge are properly designed, all the angles of incidence achievable with the array contribute to the image. The technique provides optimal detection of a planar reflector (crack-like or vertical indication) regardless of orientation when the search unit and the coupling method are properly designed.

The same FMC provides access to images corresponding to different possible UT paths (e.g., tip diffraction, corner echoes, mode conversions). Since it is possible to calculate all paths/modes from the same FMC data, when the acquisition is properly done and the features are included in the instrument, it is possible to merge different paths/modes, thus creating a reconstruction of the component and what is in it.

F-480 EVALUATION

F-481 DETECTION

TFM does not necessarily improve resolution or sensitivity, which is more dependent on the array, wedge definition, and particular method used. The potential for better resolution improves when the search unit(s) are properly designed for the examination. Also, the absolute detection capability of the FMC/TFM method can be improved when a combination of paths/modes is considered. The detection of an indication located where the flaw would otherwise be hidden by geometry is a potential advantage of this technique. Having an enhanced image usually leads to a better and more accurate interpretation of the image and the different indications within.

NONMANDATORY APPENDIX G
ALTERNATE CALIBRATION BLOCK CONFIGURATION

G-410 SCOPE

This Appendix provides guidance for using flat basic calibration blocks of various thicknesses to calibrate the examination of convex surface materials greater than 20 in. (500 mm) in diameter. An adjustment of receiver gain may be required when flat calibration blocks are used. The gain corrections apply to the far field portion of the sound beam.

G-460 CALIBRATION

G-461 DETERMINATION OF GAIN CORRECTION

To determine the required increase in gain, the ratio of the material radius, R, to the critical radius of the transducer, R_c, must be evaluated as follows.

(a) When the ratio of R/R_c, the radius of curvature of the material R divided by the critical radius of the transducer R_c from Table G-461 and Figure G-461(a), is equal to or greater than 1.0, no gain correction is required.

(b) When the ratio of R/R_c is less than 1.0, the gain correction must be obtained from Figure G-461(b).

(c) Example. Material with a 10 in. (250 mm) radius (R) will be examined with a 1 in. (25 mm) diameter 2.25 MHz boron carbide faced search unit using glycerine as a couplant.

(1) Determine the appropriate transducer factor, F_1, from Table G-461; F_1 = 92.9.

(2) Determine the R_c from Figure G-461(a); R_c = 100 in. (2 500 mm).

(3) Calculate the R/R_c ratio; 10 in./100 in. = 0.1 (250 mm/2 500 mm = 0.1).

(4) Using Figure G-461(b), obtain the gain increase required; 12 dB.

This gain increase calibrates the examination on the curved surface after establishing calibration sensitivity on a flat calibration block.

Table G-461
Transducer Factor, F_1, for Various Ultrasonic Transducer Diameters and Frequencies

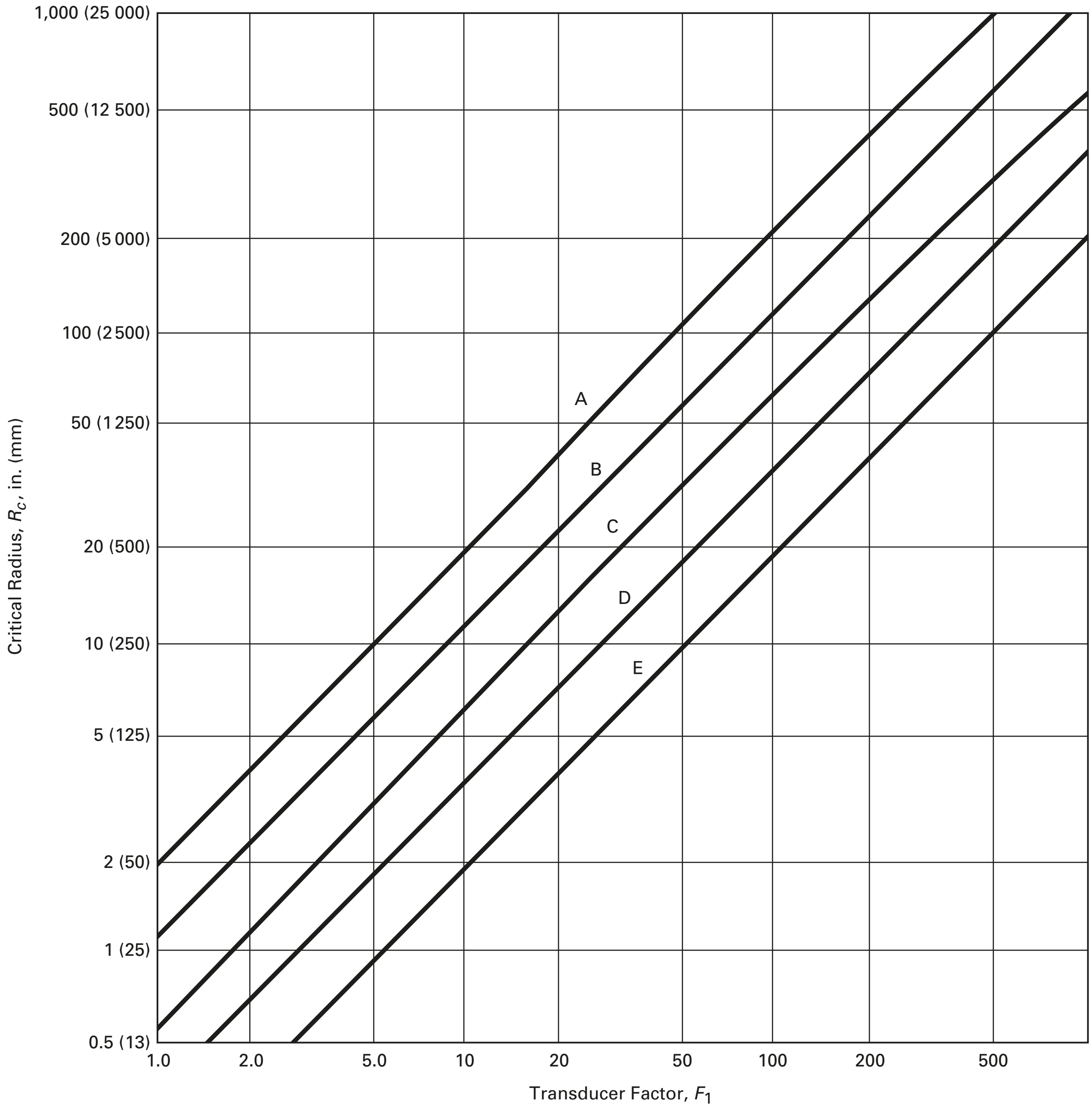
U.S. Customary Units

Frequency, MHz	Transducer Diameters, in.				
	0.25	0.5	0.75	1.0	1.125
	F_1, in.				
1.0	2.58	10.3	23.2	41.3	52.3
2.25	5.81	23.2	52.2	92.9	118
5.0	12.9	51.2	116	207	262
10.0	25.8	103	232	413	523

SI Units

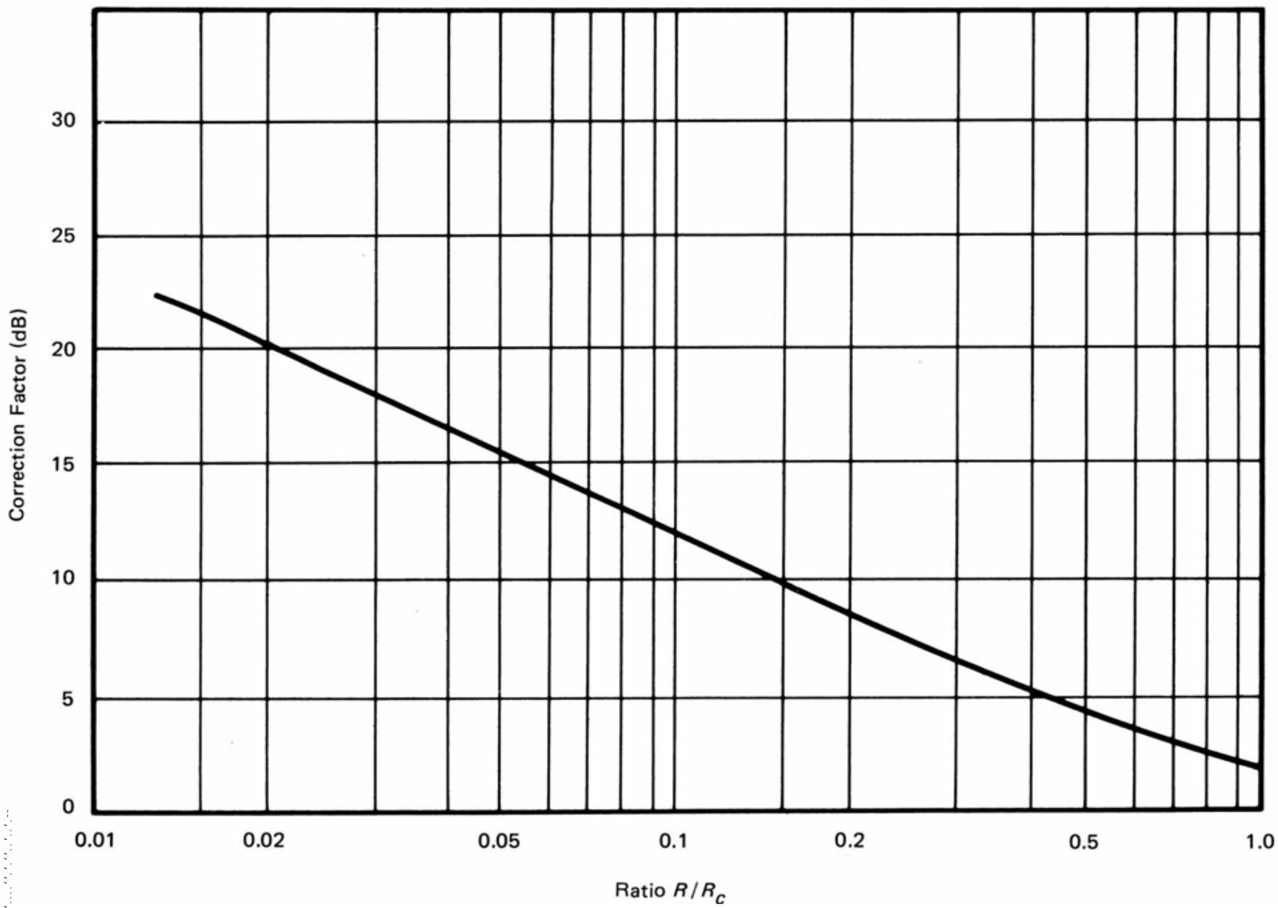
Frequency, MHz	Transducer Diameters, mm				
	6.4	13	19	25	29
	F_1, mm				
1.0	65.5	262	590	1 049	1 328
2.25	148	590	1 327	2 360	2 987
5.0	328	1 314	2 958	5 258	6 655
10.0	655	2 622	5 900	10 490	13 276

Figure G-461(a) Critical Radius, R_C, for Transducer/Couplant Combinations



Curve	Couplant	Transducer Wearface
A	Motor oil or water	Aluminum oxide or boron carbide
B	Motor oil or water	Quartz
	Glycerine or syn. ester	Aluminum oxide or boron carbide
C	Glycerine or syn. ester	Quartz
D	Motor oil or water	Plastic
E	Glycerine or syn. ester	Plastic

Figure G-461(b)
Correction Factor (Gain) for Various Ultrasonic Examination Parameters



NONMANDATORY APPENDIX I
EXAMINATION OF WELDS USING ANGLE BEAM SEARCH UNITS

I-410 SCOPE

This Appendix describes a method of examination of welds using angle beam search units.

I-470 EXAMINATION

I-471 GENERAL SCANNING REQUIREMENTS

Three angle beams, having nominal angles of 45 deg, 60 deg, and 70 deg (with respect to a perpendicular to the examination surface), shall generally be used. Beam angles other than 45 deg and 60 deg are permitted provided the measured difference between angles is at least 10 deg. Additional $t/4$ volume angle beam examination shall be conducted on the material volume within $^1/_4$ of the thickness adjacent to the examination surface. Single or dual element longitudinal or shear wave angle beams in the range of 60 deg through 70 deg (with respect to perpendicular to the examination surface) shall be used in this $t/4$ volume.

I-472 EXCEPTIONS TO GENERAL SCANNING REQUIREMENTS

Other angles may be used for examination of:

(a) flange welds, when the examination is conducted from the flange face;

(b) nozzles and nozzle welds, when the examination is conducted from the nozzle bore;

(c) attachment and support welds;

(d) examination of double taper junctures.

I-473 EXAMINATION COVERAGE

Each pass of the search unit shall overlap a minimum of 50% of the active transducer (piezoelectric element) dimension perpendicular to the direction of the scan.

NONMANDATORY APPENDIX J
ALTERNATIVE BASIC CALIBRATION BLOCK

J-410 SCOPE

This Appendix contains the description for an alternative to Article 4, T-434.2 for basic calibration blocks used for distance–amplitude correction (DAC) calibration techniques.

J-430 EQUIPMENT

J-431 BASIC CALIBRATION BLOCK

The basic calibration block(s) containing basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance–amplitude correction curve shall be as shown in Figure J-431. The basic calibration reflectors shall be located either in the component material or in a basic calibration block.

J-432 BASIC CALIBRATION BLOCK MATERIAL

(a) Block Selection. The material from which the block is fabricated shall be from one of the following:

(1) nozzle dropout from the component;

(2) a component prolongation;

(3) material of the same material specification, product form, and heat treatment condition as the material to which the search unit is applied during the examination.

(b) Clad. Where the component material is clad and the cladding is a factor during examination, the block shall be clad to the component clad nominal thickness ±$^1/_8$ in. (3 mm). Deposition of clad shall be by the same method (i.e., rollbonded, manual weld deposited, automatic wire deposited, or automatic strip deposited) as used to clad the component to be examined. When the cladding method is not known or the method of cladding used on the component is impractical for block cladding, deposition of clad may be by the manual method. When the parent materials on opposite sides of a weld are clad by either different P-, A-, or F-numbers or material designations or methods, the calibration block shall be clad with the same P-, A-, or F-numbers or material designations using the same method used on the side of the weld from which the examination will be conducted. When the examination is conducted from both sides of the weld, the calibration block shall provide for calibration for both materials and methods of cladding. For welds clad with a different material or method than the adjoining parent materials, and it is a factor during the examination, the calibration block shall be designed to be representative of this combination.

(c) Heat Treatment. The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade and a postweld heat treatment of at least 2 hr.

(d) Surface Finish. The finish on the surfaces of the block shall be representative of the surface finishes of the component.

(e) Block Quality. The calibration block material shall be completely examined with a straight beam search unit. Areas that contain indications exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

J-433 CALIBRATION REFLECTORS

(a) Basic Calibration Reflectors. The side of a hole drilled with its axis parallel to the examination surface is the basic calibration reflector. A square notch shall also be used. The reflecting surface of the notches shall be perpendicular to the block surface. See Figure J-431.

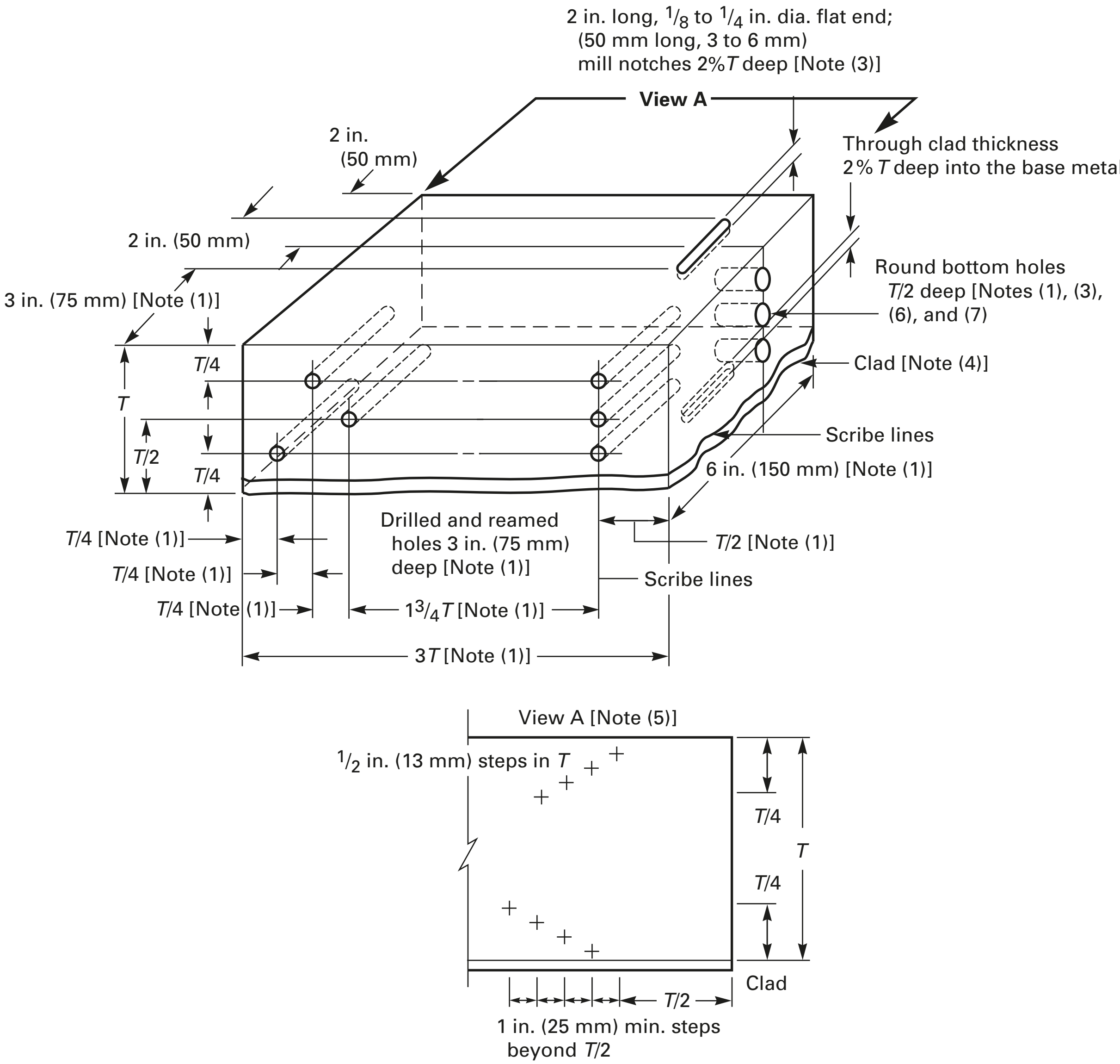
(b) Scribe Line. A scribe line as shown in Figure J-431 shall be made in the thickness direction through the in-line hole center lines and continued across the two examination surfaces of the block.

(c) Additional Reflectors. Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

(d) Basic Calibration Block Configuration. Figure J-431 shows block configuration with hole size and location. Each weld thickness on the component must be represented by a block having a thickness relative to the component weld as shown in Figure J-431. Where the block thickness ±1 in. (±25 mm) spans two of the weld thickness ranges shown in Figure J-431, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm). The holes shall be in accordance with the thickness of the block. Where two or more base material thicknesses are involved, the calibration block thickness shall be sufficient to contain the entire examination beam path.

(e) Welds in Materials With Diameters Greater Than 20 in. (500 mm). For examination of welds in materials where the examination surface diameter is greater than 20 in. (500 mm), a single curved basic calibration block may be used to calibrate the straight and angle beam examinations on surfaces in the range of curvature from 0.9

Figure J-431
Basic Calibration Block



Weld Thickness *t*, in. (mm)	Basic Calibration Block Thickness *T*, in. (mm)	Side Drilled Hole Diameter, in. (mm) [Note (3)]	Round Bottom Hole Diameter, in. (mm) [Note (3)] and [Note (6)]
Over 2 through 4 (50 through 100)	3 or *t* (75 or *t*)	3/16 (5)	3/8 (10)
Over 4 through 6 (100 through 150)	5 or *t* (125 or *t*)	1/4 (6)	7/16 (11)
Over 6 through 8 (150 through 200)	7 or *t* (175 or *t*)	5/16 (8)	1/2 (13)
Over 8 through 10 (200 through 250)	9 or *t* (225 or *t*)	3/8 (10)	9/16 (14)
Over 10 through 12 (250 through 300)	11 or *t* (275 or *t*)	7/16 (11)	5/8 (16)
Over 12 through 14 (300 through 350)	13 or *t* (325 or *t*)	1/2 (13)	11/16 (17)
Over 14 (350)	*t* ± 1 (*t* ± 25)	[Note (2)]	[Note (2)]

NOTES:
(1) Minimum dimensions.
(2) For each increase in weld thickness of 2 in. (50 mm) or fraction thereof over 14 in. (356 mm), the hole diameter shall increase 1/16 in. (1.5 mm).

Figure J-431
Basic Calibration Block (Cont'd)

NOTES (CONT'D):
(3) The tolerances for the hole diameters shall be ±$^{1}/_{32}$ in. (0.8 mm); tolerances on notch depth shall be +10 and −20% (need only be held at the thinnest clad thickness along the reflecting surface of the notch); tolerance on hole location through the thickness shall be ±$^{1}/_{8}$ in. (3 mm); perpendicular tolerances on notch reflecting surface shall be ±2 deg tolerance on notch length shall be ±$^{1}/_{4}$ in. (±6 mm).
(4) Clad shall not be included in *T*.
(5) Subsurface calibration holes $^{1}/_{8}$ in. (3 mm) (maximum) diameter by 1$^{1}/_{2}$ in. (38 mm) deep (minimum) shall be drilled at the clad-to-base metal interface and at $^{1}/_{2}$ in. (13 mm) increments through *T*/4 from the clad surface, also at $^{1}/_{2}$ in. (13 mm) from the unclad surface and at $^{1}/_{2}$ in. (13 mm) increments through *T*/4 from the unclad surface. In each case, the hole nearest the surface shall be drilled at *T*/2 from the edge of the block. Holes at $^{1}/_{2}$ in. (13 mm) thickness increments from the near surface hole shall be drilled at 1 in. (25 mm) minimum intervals from *T*/2.
(6) Round (hemispherical) bottom holes shall be drilled only when required by a Referencing Code Section for beam spread measurements (see T-434.1) and the technique of B-60 is used. The round bottom holes may be located in the largest block in a set of basic calibration blocks, or in a separate block representing the maximum thickness to be examined.
(7) *T*/2 hole may be located in the opposite end of the block.

to 1.5 times the basic calibration block diameter. Alternatively, a flat basic calibration block may be used provided the minimum convex, concave, or compound curvature radius to be examined is greater than the critical radius determined by Article 4, Nonmandatory Appendix A. For the purpose of this determination, the dimension of the straight or angle beam search units flat contact surface tangent to the minimum radius shall be used instead of the transducer diameter in Table A-10.

(f) Welds in Materials With Diameters 20 in. (500 mm) and Less. The basic calibration block shall be curved for welds in materials with diameters 20 in. (500 mm) and less. A single curved basic calibration block may be used to calibrate the examination on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (200 mm) diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. to 12 in. (180 mm to 300 mm) diameter. The curvature range from 0.94 in. to 20 in. (24 mm to 500 mm) diameter requires six block curvatures as indicated in Figure T-434.1.7.2 for any thickness range as indicated in Figure J-431.

(g) Retention and Control. All basic calibration blocks for the examination shall meet the retention and control requirements of the referencing Code Section.

NONMANDATORY APPENDIX K
RECORDING STRAIGHT BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

K-410 SCOPE

This Appendix describes a method for recording straight beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

K-470 EXAMINATION

K-471 OVERLAP

Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 50% of DAC.

K-490 RECORDS/DOCUMENTATION

Record all reflectors that produce a response equal to or greater than 50% of the distance–amplitude correction (DAC). However, clad interface and back wall reflections need not be recorded. Record all search unit position and location dimensions to the nearest tenth of an inch.

NONMANDATORY APPENDIX L
TOFD SIZING DEMONSTRATION/DUAL PROBE — COMPUTER IMAGING TECHNIQUE

L-410 SCOPE

This Appendix provides a methodology that can be used to demonstrate a UT system's ability to accurately determine the depth and length of surface machined notches originating on the examination surface from the resulting diffracted signals when a nonamplitude, Time of Flight Diffraction (TOFD), dual probe, computer imaging technique (CIT) is utilized and includes a flaw classification/sizing system.

L-420 GENERAL

Article 4 requirements apply except as modified herein.

L-430 EQUIPMENT

L-431 SYSTEM

System equipment [e.g., UT unit, computer, software, scanner(s), search unit(s), cable(s), couplant, encoder (s), etc.] shall be described in the written procedure.

L-432 DEMONSTRATION BLOCK

(a) The block material and shape (flat or curved) shall be the same as that desired to demonstrate the system's accuracy.

(b) The block shall contain a minimum of three notches machined to depths of $T/4$, $T/2$, and $3T/4$ and with lengths (L) and, if applicable, orientation as that desired to demonstrate the system's sizing accuracy. See Figure L-432 for an example.

Additional notches may be necessary depending on:

(1) the thickness of the block;

(2) the number of examination zones the block thickness is divided into;

(3) whether or not the zones are of equal thickness (for example: three zones could be broken into a top $^1/_3$, middle $^1/_3$, and bottom $^1/_3$ vs. top $^1/_4$, middle $^1/_2$, and bottom $^1/_4$); and

(4) the depths desired to be demonstrated.

(c) Prior to machining the notches, the block material through which the sound paths must travel shall be examined with the system equipment to ensure that it contains no reflectors that will interfere with the demonstration.

L-460 CALIBRATION

L-461 SYSTEM

The system shall be calibrated per the procedure to be demonstrated.

L-462 SYSTEM CHECKS

The following checks shall be performed prior to the demonstration:

(a) Positional Encoder Check. The positional encoder shall be moved through a measured distance of 20 in. (500 mm). The system read-out shall be within 1% of the measured distance. Encoders failing this check shall be re-calibrated and this check repeated.

(b) Thickness Check. A free-run shall be made on the measuring block. The distance between the lateral wave and first back-wall signal shall be +0.02 in. (+0.5 mm) of the block's measured thickness. Setups failing this check shall have the probe separation distance either adjusted or its programmed value changed and this check repeated.

L-470 EXAMINATION

The demonstration block shall be scanned per the procedure and the data recorded.

Demonstrations may be performed utilizing:

(a) D-scan (non-parallel scan) techniques

(b) B-scan (parallel scan) techniques

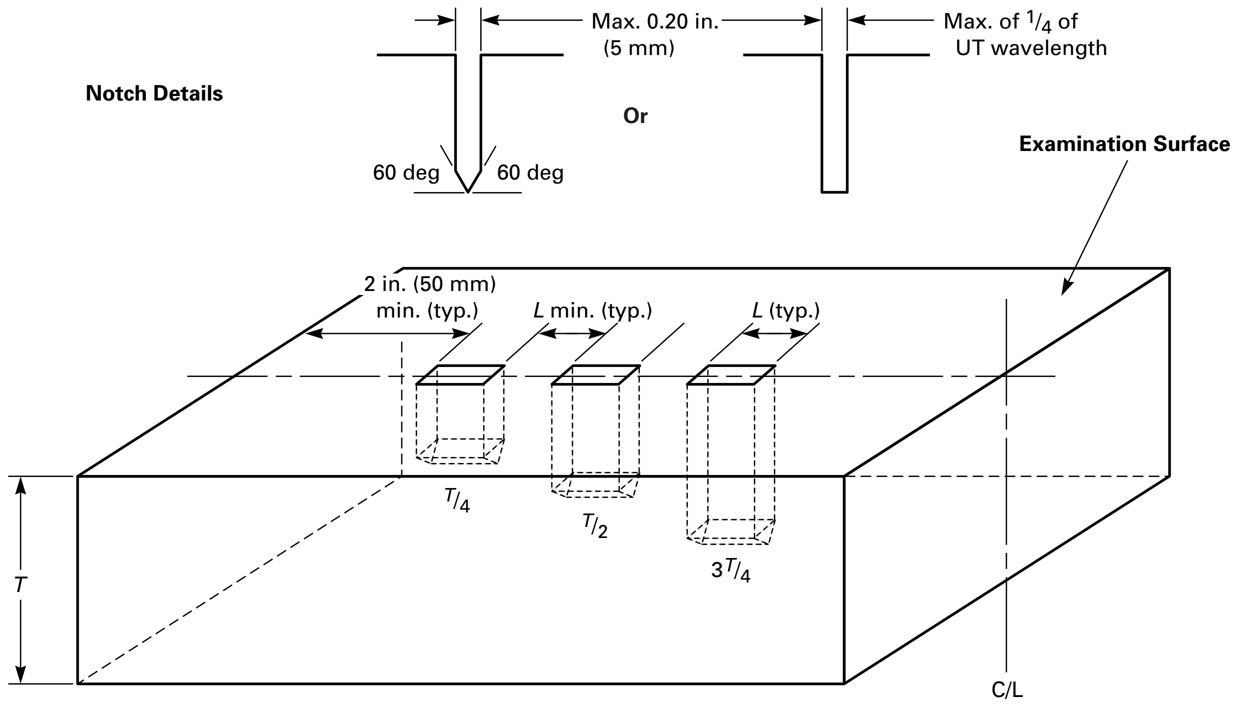
(c) D-scan (non-parallel scan) techniques with the notches offset by varying amounts to either side of being centered.

L-480 EVALUATION

L-481 SIZING DETERMINATIONS

The depth of the notches from the scanning surface and their length shall be determined per the procedure to be demonstrated.

Figure L-432
Example of a Flat Demonstration Block Containing Three Notches



GENERAL NOTE: Block length and width to be adequate for UT System Scanner.

L-482 SIZING ACCURACY DETERMINATIONS

Sizing accuracy (%) shall be determined by the following equations:

(a) Depth:

$$\frac{D_d - D_m}{D_m} \times 100$$

(b) Length:

$$\frac{L_d - L_m}{L_m} \times 100$$

where D_d and L_d are the notches' depth and lengths, respectively, as determined by the UT system being demonstrated, and

D_m and L_m are the notches' depth and lengths, respectively, as determined by physical measurement (i.e., such as replication)

NOTE: Use consistent units.

L-483 CLASSIFICATION/SIZING SYSTEM

L-483.1 Sizing. Flaws shall be classified as follows:

(a) Top-Surface Connected Flaws. Flaw indications consisting solely of a lower-tip diffracted signal and with an associated weakening, shift, or interruption of the lateral wave signal, shall be considered as extending to the top-surface unless further evaluated by other NDE methods.

(b) Embedded Flaws. Flaw indications with both an upper and lower-tip diffracted signal or solely an upper-tip diffracted signal and with no associated weakening, shift, or interruption of the back-wall signal shall be considered embedded.

(c) Bottom-Surface Connected Flaws. Flaw indications consisting solely of an upper-tip diffracted signal and with an associated shift of the backwall or interruption of the back-wall signal, shall be considered as extending to the bottom surface unless further evaluated by other NDE methods.

L-483.2 Flaw Height Determination. Flaw height (thru-wall dimension) shall be determined as follows:

(a) Top-Surface Connected Flaws. The height of a top-surface connected flaw shall be determined by the distance between the top-surface lateral wave and the lower-tip diffracted signal.

(b) Embedded Flaws. The height (h) of an embedded flaw shall be determined by:

(1) the distance between the upper-tip diffracted signal and the lower-tip diffracted signal or

(2) the following calculation for flaws with just a singular upper-tip diffracted signal:

$$h = \left[\left(c \left(t_d + t_p \right) / 2 \right)^2 - s^2 \right)\Big]^{1/2} - d$$

where

c = longitudinal sound velocity
d = depth of the flaw below the scanning surface
s = half the distance between the two probes' index points
t_d = the time-of-flight at depth d
t_p = the length of the acoustic pulse

NOTE: Use consistent units.

(c) Bottom-Surface Connected Flaws. The height of a bottom-surface connected flaw shall be determined by the distance between the upper-tip diffracted signal and the back-wall signal.

L-483.3 Flaw Length Determination. The flaw length shall be determined by the distance between end fitting hyperbolic cursurs or the flaw end points after a synthetic aperture focusing technique (SAFT) program has been run on the data.

L-490 DOCUMENTATION

L-491 DEMONSTRATION REPORT

In addition to the applicable items in T-492, the report of demonstration shall contain the following information:

(a) computerized program identification and revision;

(b) mode(s) of wave propagation used;

(c) demonstration block configuration (material, thickness, and curvature);

(d) notch depths, lengths, and, if applicable, orientation (i.e., axial or circumferential);

(e) instrument settings and scanning data;

(f) accuracy results.

NONMANDATORY APPENDIX M
GENERAL TECHNIQUES FOR ANGLE BEAM LONGITUDINAL WAVE CALIBRATIONS

M-410 SCOPE

This Appendix provides general techniques for angle beam longitudinal wave calibration. Other techniques may be used. The sweep range may be calibrated in terms of metal path, projected surface distance, or actual depth to the reflector. The particular method may be selected according to the preference of the examiner.

Angle beam longitudinal wave search units are normally limited to $^1/_2$V-path calibrations, since there is a substantial loss in beam energy upon reflection due to mode conversion.

M-460 CALIBRATION

M-461 SWEEP RANGE CALIBRATION

M-461.1 Side-Drilled Holes (See Figure M-461.1).

NOTE: This technique provides sweep calibration for depth.

M-461.1.1 Delay Control Adjustment. Position the search unit for the maximum indication from the $^1/_4T$ side-drilled hole (SDH). Adjust the left edge of this indication to line 2 on the screen with the delay control.

M-461.1.2 Range Control Adjustment.[14] Position the search unit for the maximum indication from the $^3/_4T$ SDH. Adjust the left edge of this indication to line 6 on the screen with the range control.

M-461.1.3 Repeat Adjustments. Repeat delay and range adjustments until the $^1/_4T$ and $^3/_4T$ SDH indications start at sweep lines 2 and 6.

M-461.1.4 Sweep Readings. Two divisions on the sweep now equal $^1/_4T$.

M-461.2 Cylindrical Surface Reference Blocks (See Figure M-461.2).

NOTE: This technique provides sweep calibration for metal path.

M-461.2.1 Delay Control Adjustment. Position the search unit for the maximum indication from the 1 in. (25 mm) cylindrical surface. Adjust the left edge of this indication to line 5 on the screen with the delay control.

M-461.2.2 Range Control Adjustment. Position the search unit for the maximum indication from the 2 in. (50 mm) cylindrical surface. Adjust the left edge of this indication to line 10 on the screen with the range control.

M-461.2.3 Repeat Adjustments. Repeat delay and range control adjustments until the 1 in. (25 mm) and 2 in. (50 mm) indications start at sweep lines 5 and 10.

Figure M-461.1
Sweep Range (Side-Drilled Holes)

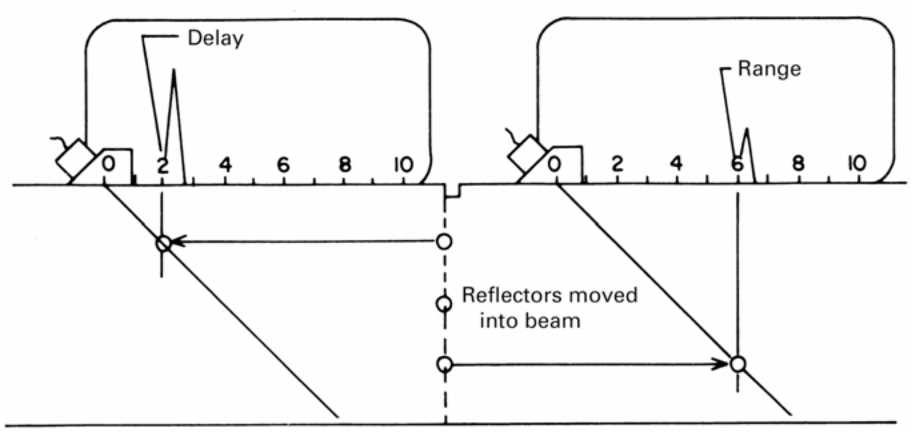
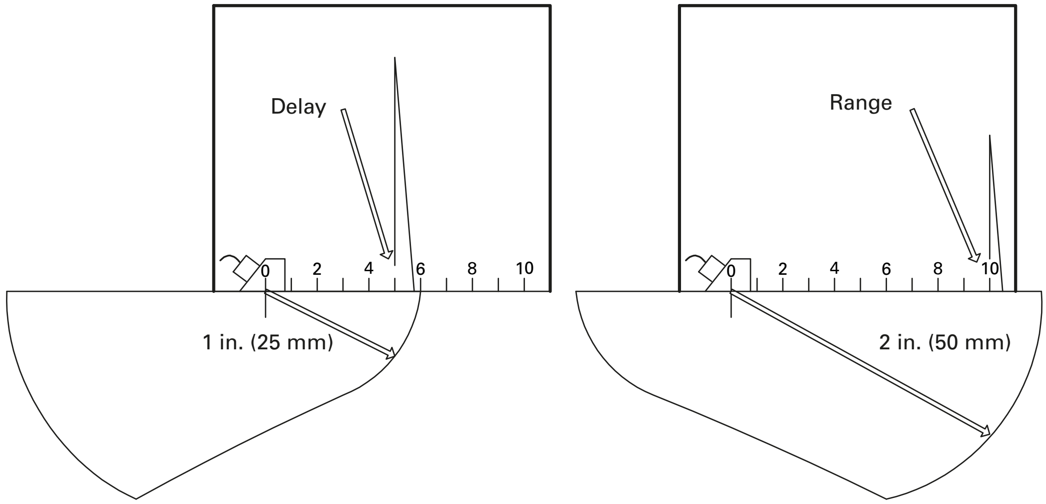


Figure M-461.2
Sweep Range (Cylindrical Surfaces)



M-461.2.4 Sweep Readings. The sweep now represents 2 in. (50 mm) of sound path distance.

M-461.3 Straight Beam Search Unit and Reference Blocks (See Figure M-461.3).

NOTE: This technique provides sweep calibration for metal path.

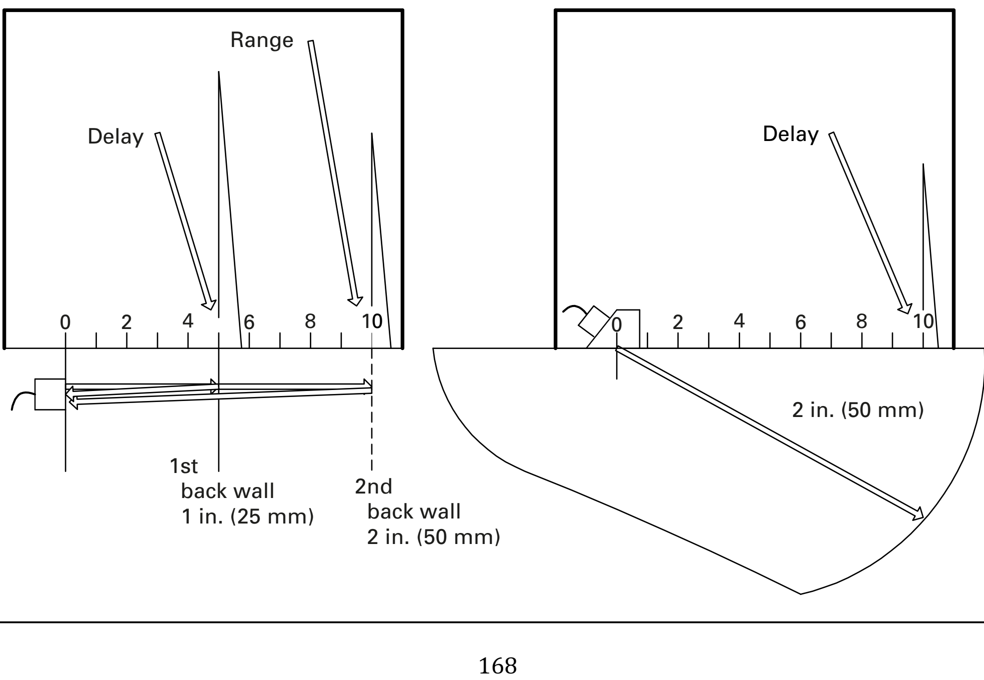
M-461.3.1 Search Unit Placement. Position a straight beam search unit on a 1 in. (25 mm) thick reference block so as to display multiple back-wall indications.

M-461.3.2 Delay Control Adjustment. Adjust the left edge of the first back-wall indication to line 5 on the screen with the delay control.

M-461.3.3 Range Control Adjustment. Adjust the left edge of the second back-wall indication to line 10 on the screen with the range control.

M-461.3.4 Repeat Adjustments. Repeat delay and range control adjustments until the 1 in. (25 mm) and 2 in. (50 mm) indications start at sweep lines 5 and 10.

Figure M-461.3
Sweep Range (Straight Beam Search Unit)



M-461.3.5 Final Delay Adjustment. Remove the straight beam search unit from the coaxial cable and connect the angle beam search unit to the system. Position the search unit for the maximum indication from the 2 in. (50 mm) cylindrical surface. Adjust the left edge of this indication to line 10 on the screen with the delay control.

M-461.3.6 Sweep Readings. The sweep now represents 2 in. (50 mm) of sound path distance.

M-462 DISTANCE–AMPLITUDE CORRECTION (DAC) (SEE FIGURE M-462)

(a) Position the search unit for maximum response from the SDH that gives the highest amplitude.

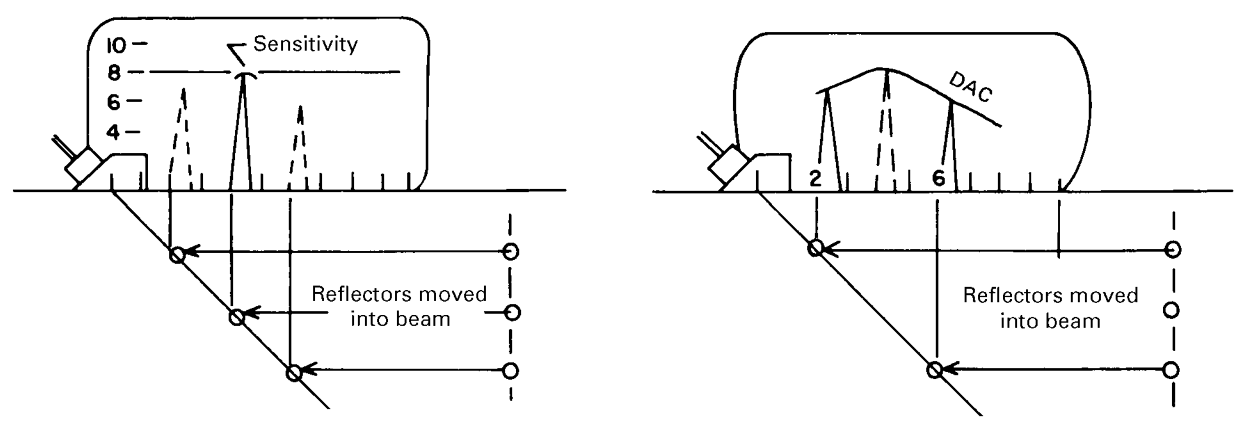
(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height. This is the primary reference level. Mark the peak of this indication on the screen.

(c) Position the search unit for maximum response from another SDH and mark the peak of the indication on the screen.

(d) Position the search unit for maximum response from the third SDH and mark the peak on the screen.

(e) Connect the screen marks of the SDHs to provide the DAC curve.

Figure M-462
Sensitivity and Distance–Amplitude Correction



(a) Sensitivity **(b) Distance Amplitude**

NONMANDATORY APPENDIX N
TIME OF FLIGHT DIFFRACTION (TOFD) INTERPRETATION

N-410 SCOPE

This Appendix is to be used as an aid for the interpretation of Time of Flight Diffraction (TOFD) ultrasonic images. Diffraction is a common ultrasonic phenomenon and occurs under much broader conditions than just longitudinal-longitudinal diffraction as used in typical TOFD examinations. This interpretation guide is primarily aimed at longitudinal-longitudinal diffraction TOFD setups using separated transducers on either side of the weld on a plate, pipe, or curved vessel. Other possibilities include:

(a) shear-shear diffraction

(b) longitudinal-shear diffraction

(c) single transducer diffraction (called "back diffraction" or the "tip-echo method"

(d) twin transducer TOFD with both transducers on the same side of the flaw/weld

(e) complex inspections, e.g., nozzles

N-420 GENERAL

N-421 TOFD IMAGES — DATA VISUALIZATION

(a) TOFD data is routinely displayed as a grayscale image of the digitized A-scan. Figure N-421(a) shows the grayscale derivation of an A-scan (or waveform) signal.

(b) TOFD images are generated by the stacking of these grayscale transformed A-scans as shown in Figure N-421(b). The lateral wave and backwall signals are visible as continuous multicycle lines. The midwall flaw shown consists of a visible upper and lower tip signal. These show as intermediate multicycle signals between the lateral wave and the backwall.

(c) TOFD grayscale images display phase changes, some signals are white-black-white; others are black-white-black. This permits identification of the wave source (flaw top or bottom, etc.), as well as being used for flaw sizing. Depending on the phase of the incident pulse (usually a negative voltage), the lateral wave would be positive, then the first diffracted (upper tip) signal negative, the second diffracted (lower tip) signal positive, and the backwall signal negative. This is shown schematically in Figure N-421(c). This phase information is very useful for signal interpretation; consequently, RF signals and unrectified signals are used for TOFD. The phase information is used for correctly identifying signals (usually the top and bottom of flaws, if they can be differentiated), and for determining the correct location for depth measurements.

Figure N-421(a)
Schematic Showing Waveform Transformation Into Grayscale

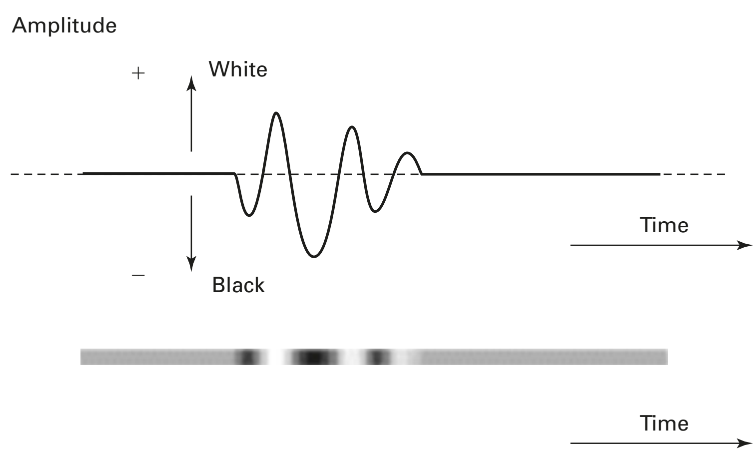


Figure N-421(b) Schematic Showing Generation of Grayscale Image From Multiple A-Scans

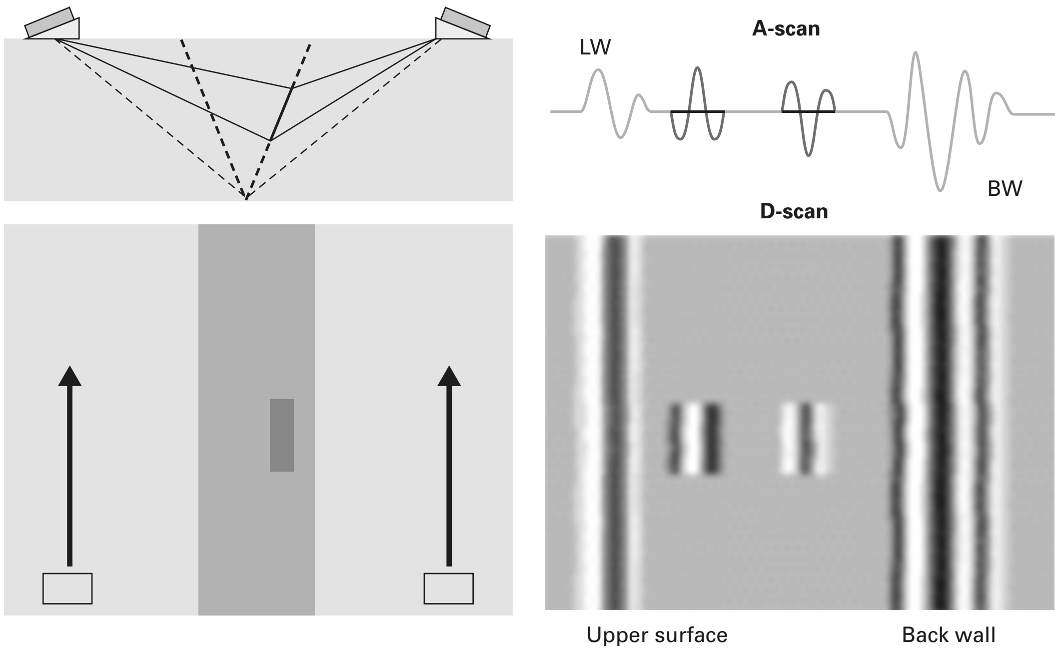
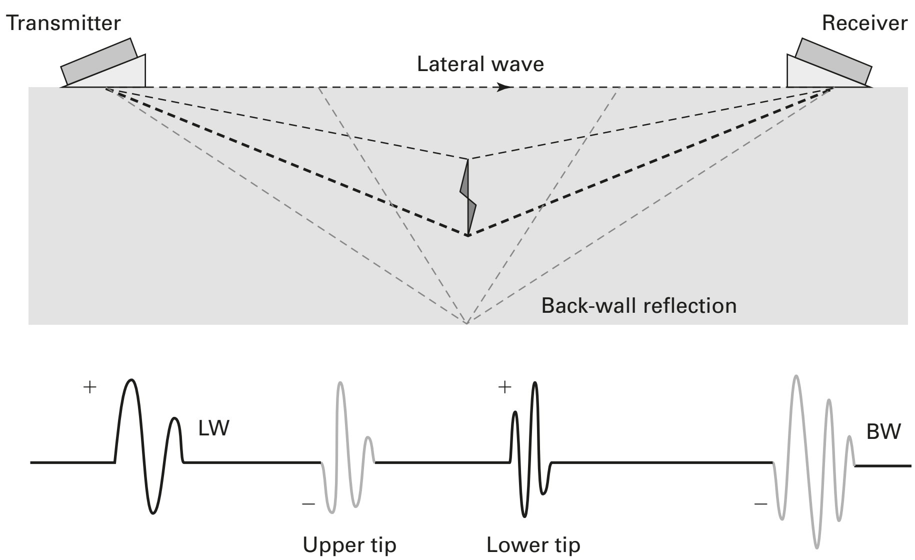


Figure N-421(c) Schematic Showing Standard TOFD Setup and Display With Waveform and Signal Phases



(d) An actual TOFD image is shown in Figure N-421(d), with flaws. The time-base is horizontal and the axis of motion is vertical [the same as the schematic in Figure N-421(c)]. The lateral wave is the fairly strong multicycle pulse at left, and the backwall the strong multicycle pulse at right. The flaws show as multicycle gray and white reflections between the lateral and backwall signals. The scan shows several separate flaws (incomplete fusion, porosity, and slag). The ultrasonic noise usually comes from grain reflections, which limits the practical frequency that can be used. TOFD scans may only show the lateral wave (O.D.) and backwall (I.D.), with "noise." There is also ultrasonic information available past the backwall (typically shear wave diffractions), but this is generally not used.

N-450 PROCEDURE

N-451 MEASUREMENT TOOLS

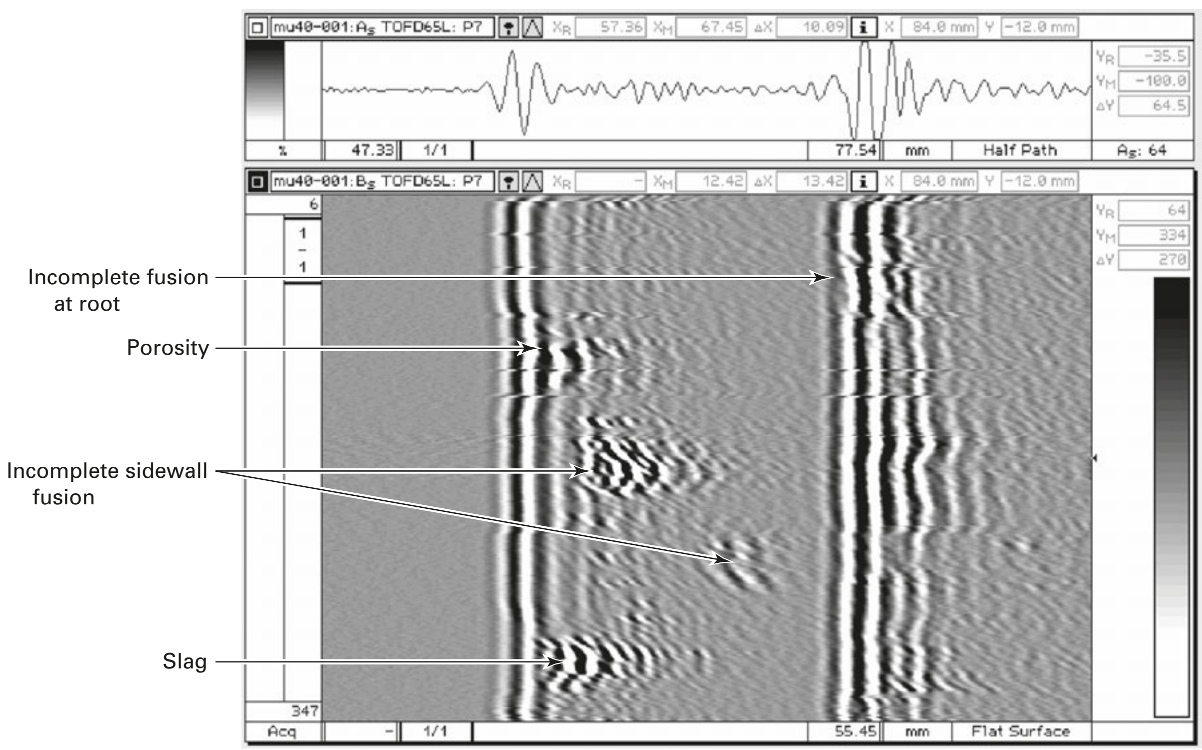
TOFD variables are probe spacing, material thickness, sound velocity, transducer delay, and lateral wave transit and backwall reflection arrival time. Not all the variables need to be known for flaw sizing. For example, calibration using just the lateral wave (front wall or O.D.) and backwall (I.D.) signals can be performed without knowing the transducers delay, separation, or velocity. The arrival time, Figure N-451, of the lateral wave (t_1) and the backwall signal (t_2) are entered into the computer software and cursors are then displayed for automated sizing.

N-452 FLAW POSITION ERRORS

Flaws will not always be symmetrically placed between the transmitter and receiver transducers. Normally, a single pair of transducers is used, centered on the weld axis. However, multiple TOFD sets can be used, particularly on heavy wall vessels, and offsets are used to give improved detection. Also, flaws do not normally occur on the weld centerline. Either way, the flaws will not be positioned symmetrically, Figure N-452(a) and this will be a source or error in location and sizing.

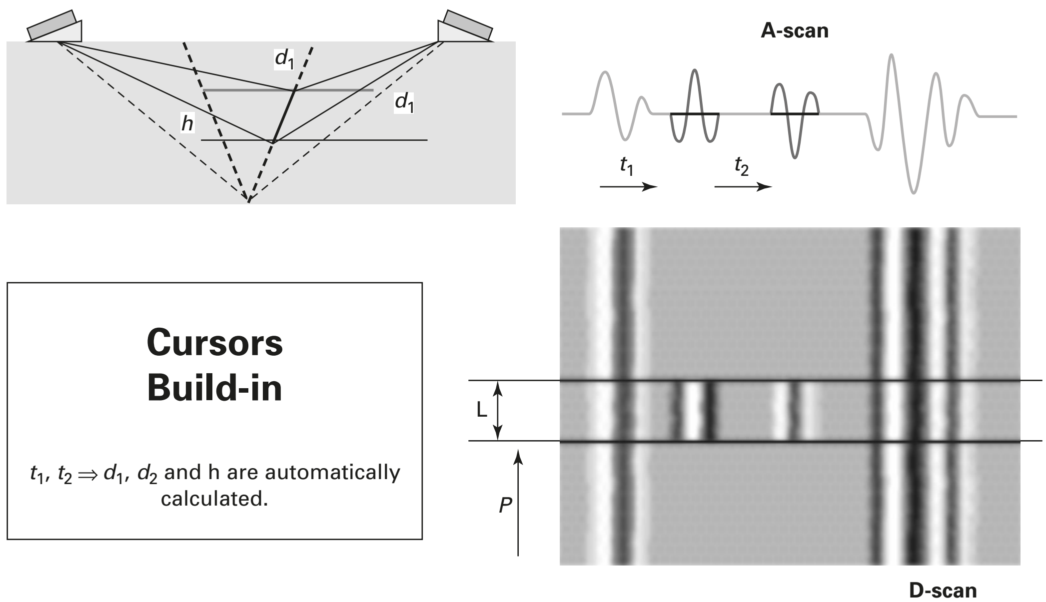
There will be positional and sizing errors associated with a noncentered flaw, as shown in Figure N-452(b). However, these errors will be small, and generally are tolerable since the maximum error due to off-axis position is less than 10% and the error is actually smaller yet since both the top and bottom of the flaw are offset by similar amounts. The biggest sizing problems occur with small flaws near the backwall. Exact error values will depend on the inspection parameters.

Figure N-421(d)
TOFD Display With Flaws and Displayed A-Scan



GENERAL NOTE: Time is horizontal and the axis of motion is vertical.

Figure N-451
Measurement Tools for Flaw Heights



N-453 MEASURING FLAW LENGTH

Flaw lengths parallel to the surface can be measured from the TOFD image by fitting hyperbolic cursors to the ends of the flaws (see Figure N-453).

N-454 MEASURING FLAW DEPTH

Flaw height perpendicular to the surface can be measured from the TOFD image by fitting cursors on the top and bottom tip signals. The following are two examples of depth measurements of weld flaws in a 1 in. (25 mm) thick plate. Figure N-454(a) is midwall lack of fusion and Figure N-454(b) is a centerline crack. Note that TOFD signals are not linear, so midwall flaws show in the upper third region of the image. It is possible to linearize the TOFD scans by computer software.

N-480 EVALUATION

This section shows a variety of TOFD images and the interpretation/explanation. Unfortunately, there are significant variations amongst flaws and TOFD setups and displays, so the following images should be used as a guide only. Evaluator experience and analysis skills are very important as well.

N-481 SINGLE FLAW IMAGES

(a) Point flaws [Figure N-481(a)], like porosity, show up as single multicycle points between the lateral and backwall signals. Point flaws typically display a single TOFD signal since flaw heights are smaller than the ringdown of the pulse (usually a few millimeters, depending

Figure N-452(a)
Schematic Showing the Detection of Off-Axis Flaws

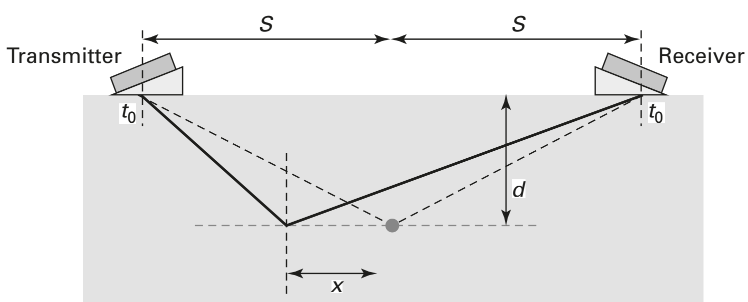
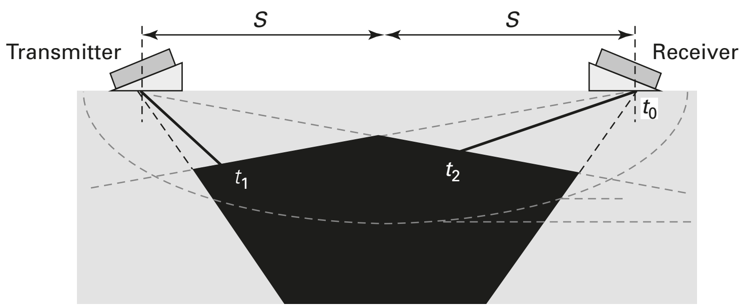


Figure N-452(b)
Measurement Errors From Flaw Position Uncertainty



Flaw Position Uncertainty

GENERAL NOTE: In practice, the maximum error on absolute depth position lies below 10%. The error on height estimation of internal (small) flaws is negligible. Be careful of small flaws situated at the backwall.

on the transducer frequency and damping). Point flaws usually show parabolic "tails" where the signal drops off towards the backwall.

(b) Inside (I.D.) far-surface-breaking flaws [Figure N-481(b)] shows no interruption of the lateral wave, a signal near the backwall, and a related interruption or break of the backwall (depending on flaw size).

(c) Near-surface-breaking flaws [Figure N-481(c)] shows perturbations in the lateral wave. The flaw breaks the lateral wave, so TOFD can be used to determine if the flaw is surface-breaking or not. The lower signal can then be used to measure the depth of the flaw. If the flaw is not surface-breaking, i.e., just subsurface, the lateral wave will not be broken. If the flaw is near-subsurface and shallow (that is, less than the ringing time of the lateral wave or a few millimeters deep), then the flaw will probably be invisible to TOFD. The image also displays a number of signals from point flaws.

(d) Midwall flaws [Figure N-481(d)] show complete lateral and backwall signals, plus diffraction signals from the top and bottom of the flaw. The flaw tip echoes provide a very good profile of the actual flaw. Flaw sizes can be readily black-white, while the lower echo is black-white-black. Also note the hyperbolic curve that is easily visible at the left end of the top echo; this is similar to the effect from a point flaw [see N-481(a)] and permits accurate length measurement of flaws [see N-450(a)].

If a midwall flaw is shallow, i.e., less than the transducer pulse ring-down (a few millimeters), the top and bottom tip signals cannot be separated. Under these circumstances, it is not possible to differentiate the top from the bottom of the flaw, so the evaluator can only

Figure N-453
TOFD Image Showing Hyperbolic "Tails" From the Ends of a Flaw Image Used to Measure Flaw Length

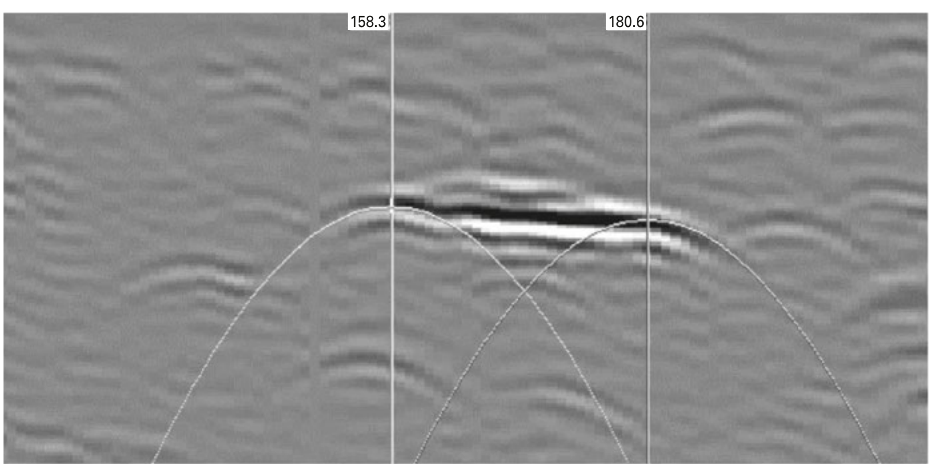


Figure N-454(a)
TOFD Image Showing Top and Bottom Diffracted Signals From Midwall Flaw and A-Scan Interpretation

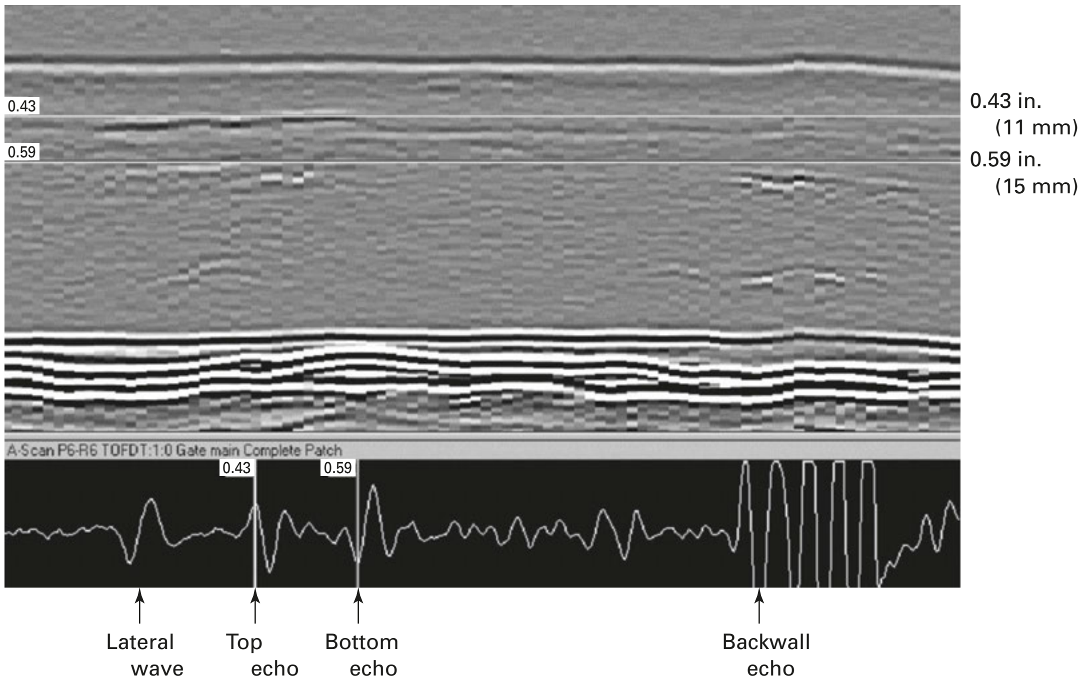


Figure N-454(b)
TOFD Image Showing Top and Bottom Diffracted Signals From Centerline Crack and A-Scan Interpretation

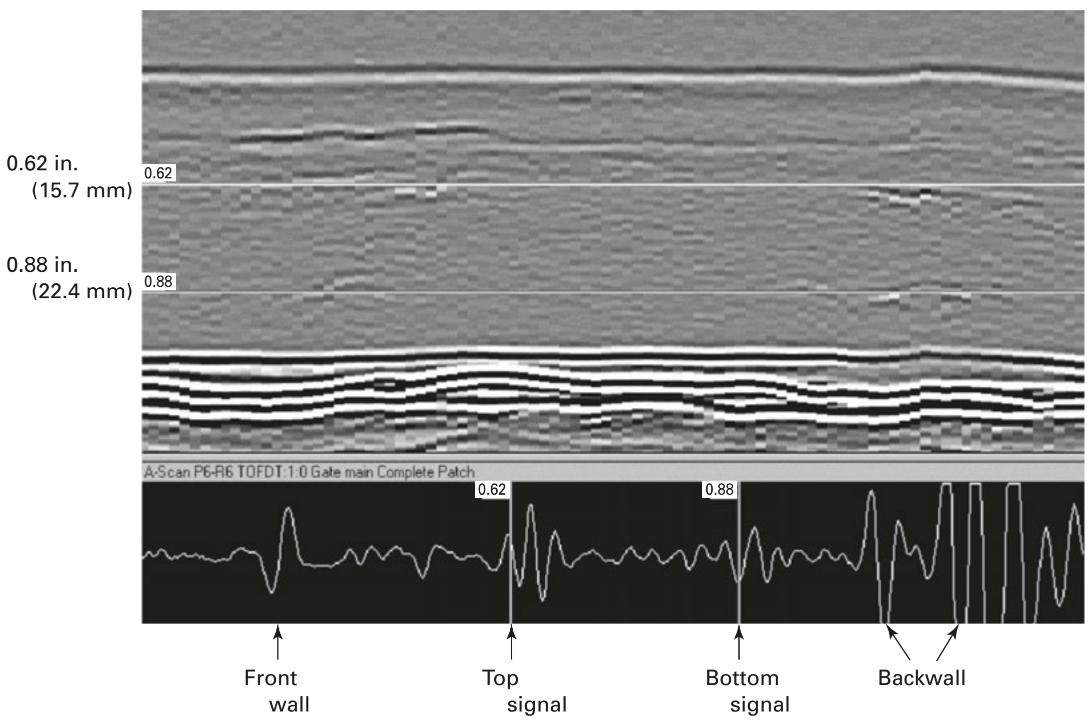
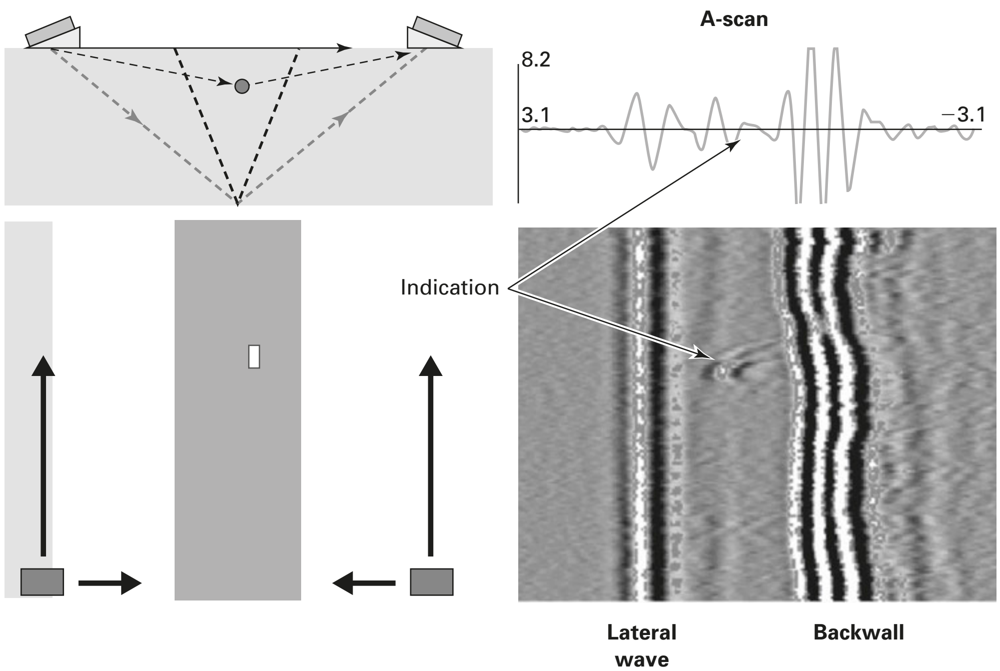


Figure N-481(a)
Schematics of Image Generation, Scan Pattern, Waveform, and TOFD Display Showing the Image of the Point Flaw



say that the flaw is less than the ringdown distance (which depends on transducer frequency and damping, etc.).

(e) Lack of root penetration [see Figure N-481(e)] is similar to an inside (I.D.) far-surface-breaking flaw [see N-481(b)]. This flaw gives a strong diffracted signal (or more correctly, a reflected signal) with a phase inversion from the backwall signal. Note that whether signals are diffracted or reflected is not important for TOFD characterization; the analysis and sizing is the same. Also note even though there is a perturbation of the backwall signal, the backwall is still visible across the whole flaw. This material also shows small point flaws and some grain noise, which is quite common. TOFD typically overemphasizes small point flaws, which are normally undetected by conventional shear wave pulse-echo techniques.

(f) Concave root flaws [see Figure N-481(f)] are similar to lack of root penetration. The top of the flaw is visible in the TOFD image, as well as the general shape. The backwall signal shows some perturbation as expected.

(g) Sidewall lack of fusion [see Figure N-481(g)] is similar to a midwall flaw [see N-481(d)] with two differences. First, the flaw is angled along the fusion line, so TOFD is effectively independent of orientation, which is not a problem for TOFD. Second, the upper flaw signal is partly buried in the lateral wave for this particular flaw. In this instance, the upper tip signal is detectable since the lateral wave signal amplitude is noticeably increased. However, if this were not the case, then the evaluator would be unable to accurately measure the flaw depth.

(h) Porosity [see Figure N-481(h)] appears as a series of hyperbolic curves of varying amplitudes, similar to the point flaw [see N-481(a)]. The TOFD hyperbolic curves are superimposed since the individual porosity pores are closely spaced. This does not permit accurate analysis, but the unique nature of the image permits characterization of the signals as "multiple small point flaws," i.e., porosity.

(i) Transverse cracks [see Figure N-481(i)] are similar to a point flaw [see N-481(a)]. The TOFD scan displays a typical hyperbola. Normally, it would not be possible to differentiate transverse cracks from near-surface porosity using TOFD; further inspection would be needed.

(j) Interpass lack of fusion [see Figure N-481(j)] shows as a single, high amplitude signal in the midwall region. If the signal is long, it is easily differentiated from porosity or point sources. It is not possible to distinguish the top and bottom, as these do not exist as such. Note the expected phase change from the lateral wave. Interpass lack of fusion signals are generally benign.

Figure N-481(b)
Schematics of Image Generation, Flaw Location, and TOFD Display Showing the Image of the Inside (ID) Surface-Breaking Flaw

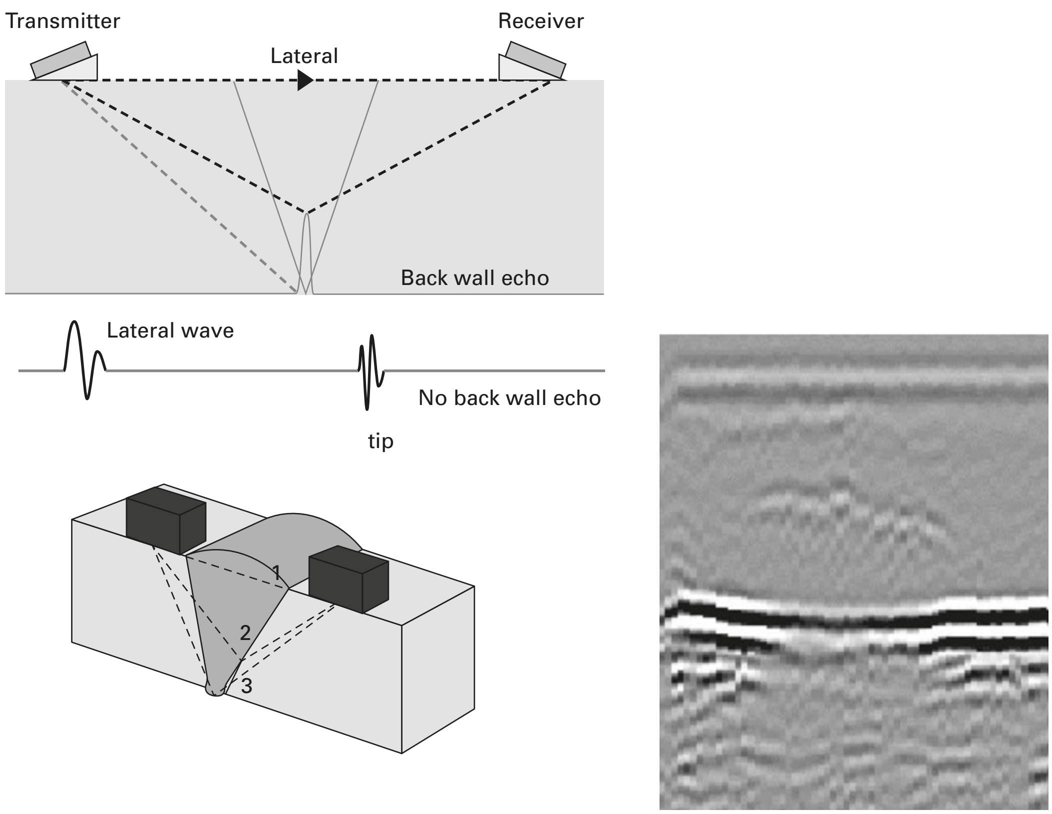


Figure N-481(c)
Schematics of Image Generation, Flaw Location, and TOFD Display Showing the Image of the Outside (OD) Surface-Breaking Flaw

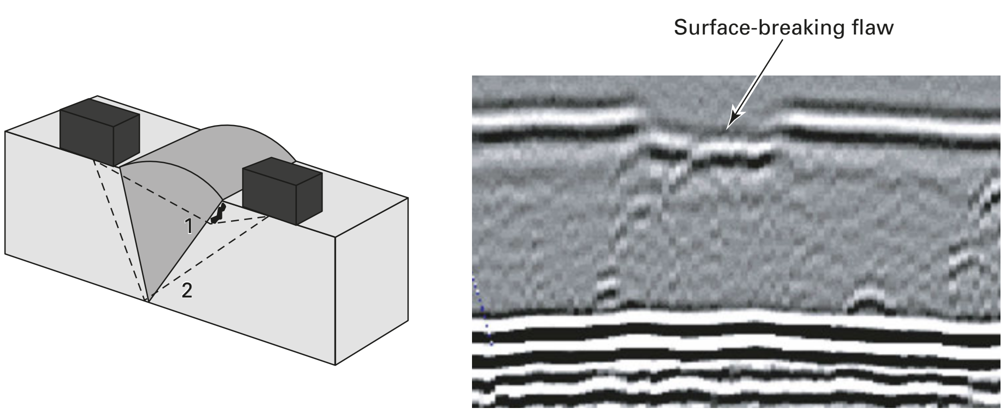


Figure N-481(d)
Schematics of Flaw Location, Signals, and TOFD Display Showing the Image of the Midwall Flaw

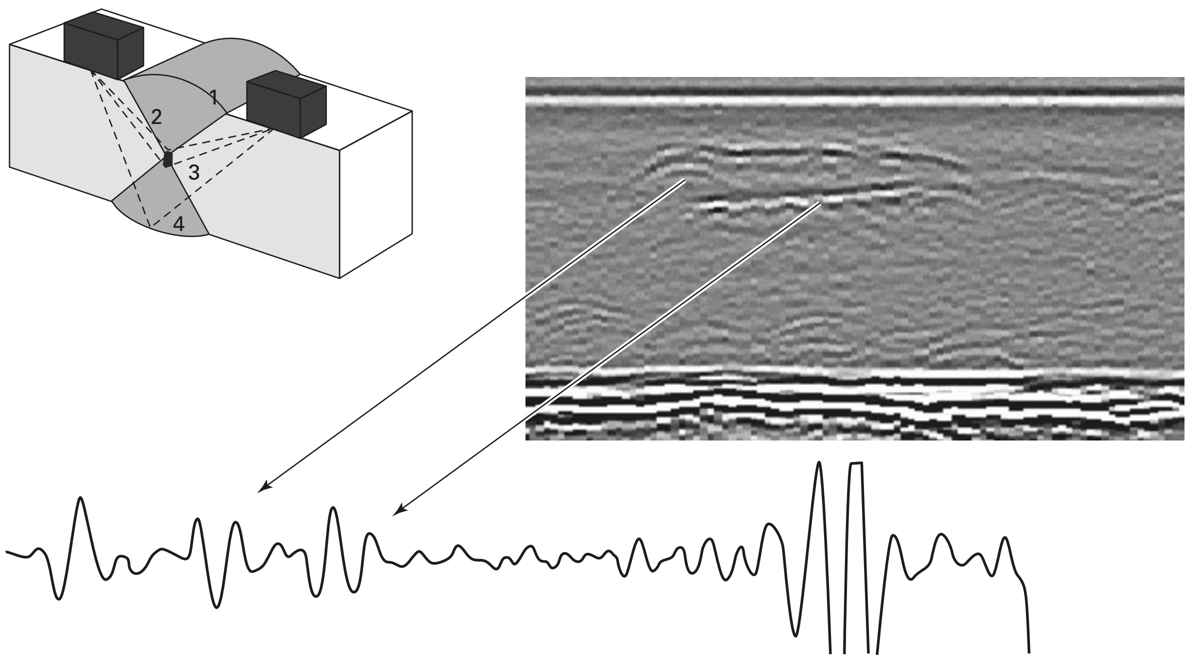


Figure N-481(e)
Flaw Location and TOFD Display Showing the Image of the Lack of Root Penetration

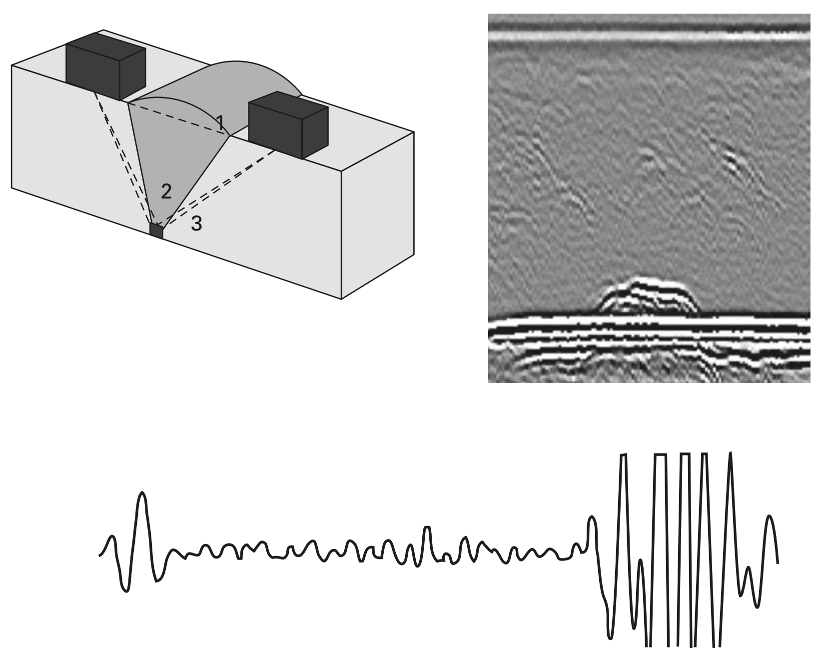


Figure N-481(f)
Flaw Location and TOFD Display Showing the Image of the Concave Root Flaw

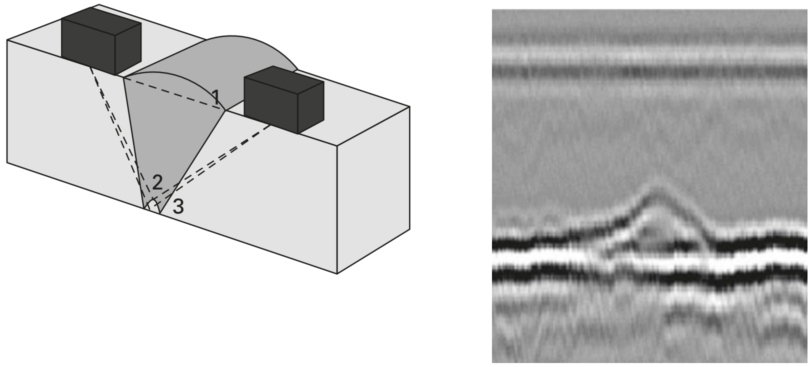


Figure N-481(g)
Flaw Location, TOFD Display Showing the Image of the Midwall Lack of Fusion Flaw, and the A-Scan

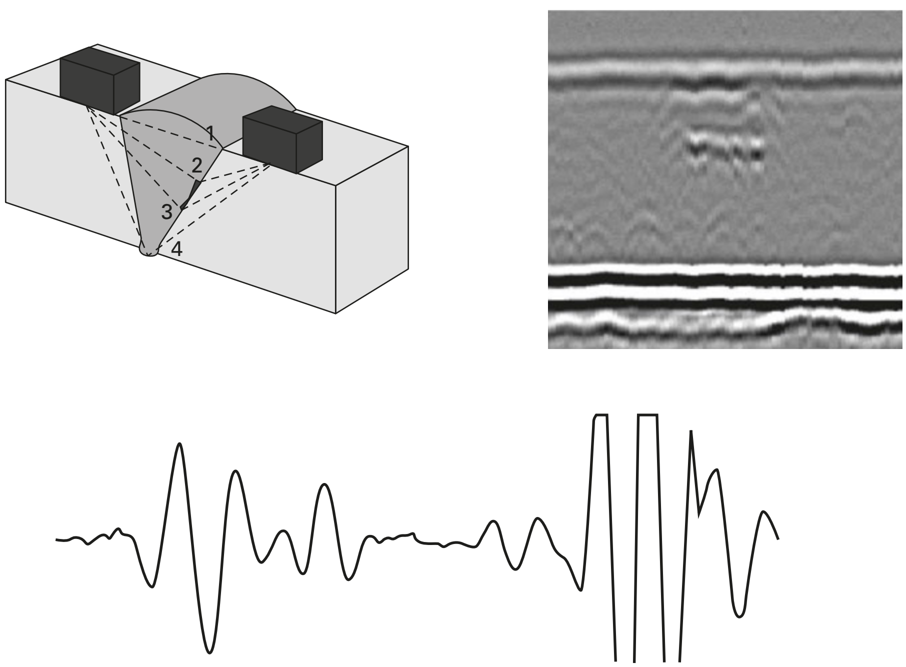


Figure N-481(h)
Flaw Location and TOFD Display Showing the Image of the Porosity

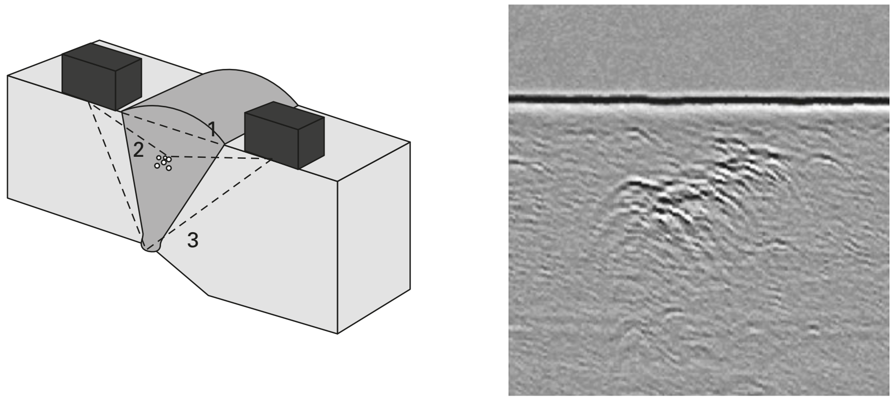


Figure N-481(i)
Flaw Location and TOFD Display Showing the Image of the Transverse Crack

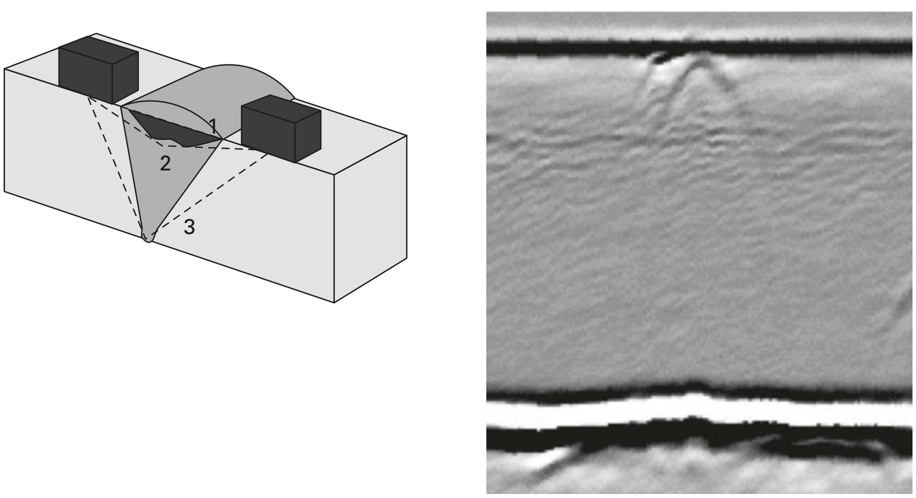
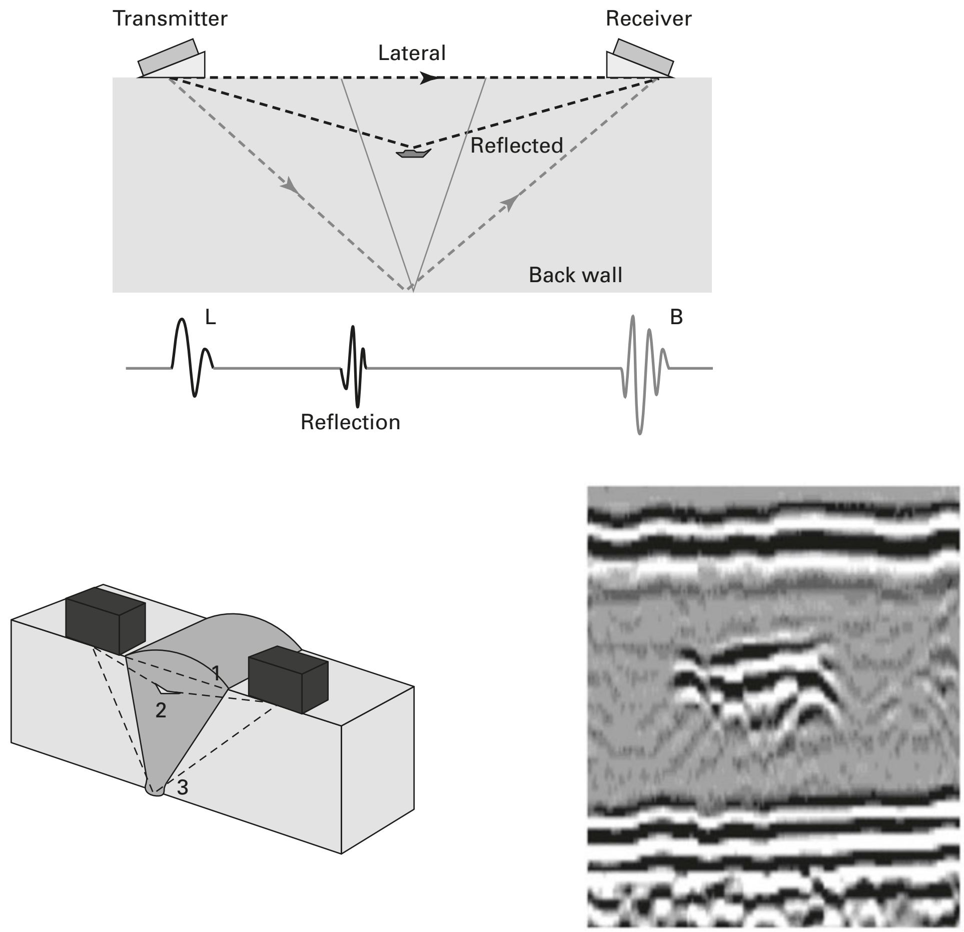


Figure N-481(j)
Schematics of Image Generation, Flaw Location, and TOFD Display Showing the Image of the Interpass Lack of Fusion



N-482 MULTIPLE FLAW IMAGES

TOFD images of flawed welds contain four flaws each.

N-482.1 Plate 1 [Figure N-482(a)]. Figure N-482(a) clearly illustrates the significant advantages of TOFD (midwall flaw detection, flaw sizing), the limitations due to dead zones, and that

(a) the sidewall incomplete fusion shows up clearly, as does the slag.

(b) the incomplete fusion at the root was not easily detected, though it did disturb the backwall. This is not surprising in the backwall dead zone due to a shear-shear diffracted wave. This example illustrates the potential value of using information later in the time base, but this is outside the scope of this interpretation manual.

(c) the root crack is not visible at all due to the backwall dead zone.

N-482.2 Plate 2 [Figure N-482(b)]. Figure N-482(b) shows that:

(a) all four flaws are detectable

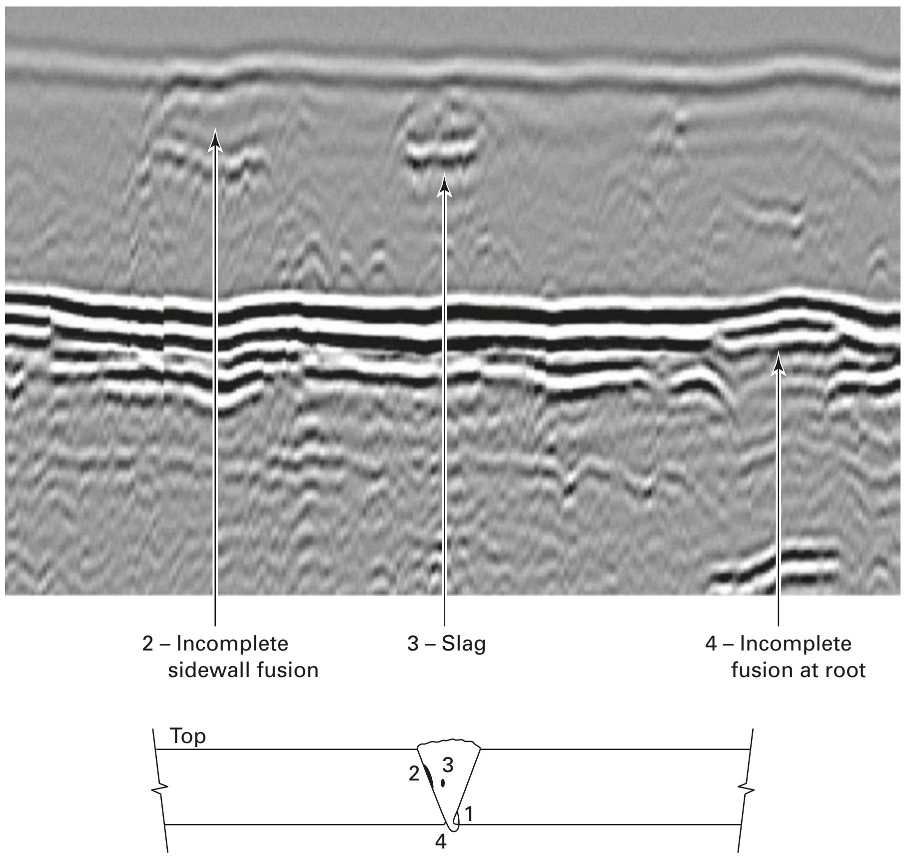
(b) the incomplete fusion at the root shows up clearly in this scan because it is deeper. Both the backwall perturbation and the flaw tip signals are clear.

(c) the crown toe crack is clearly visible, both by complete disruption of the lateral wave and by the bottom tip signal. Both the incomplete fusion at the root and crown toe crack are identifiable as surface-breaking by the disruption of the lateral wave and backwall signal, respectively.

(d) the porosity is visible as a series of signals. This cluster of porosity would be difficult to characterize properly using the TOFD scan alone, since it could be identified as slag or a planar flaw.

(e) the incomplete sidewall fusion is clearly visible and could be easily sized using cursors.

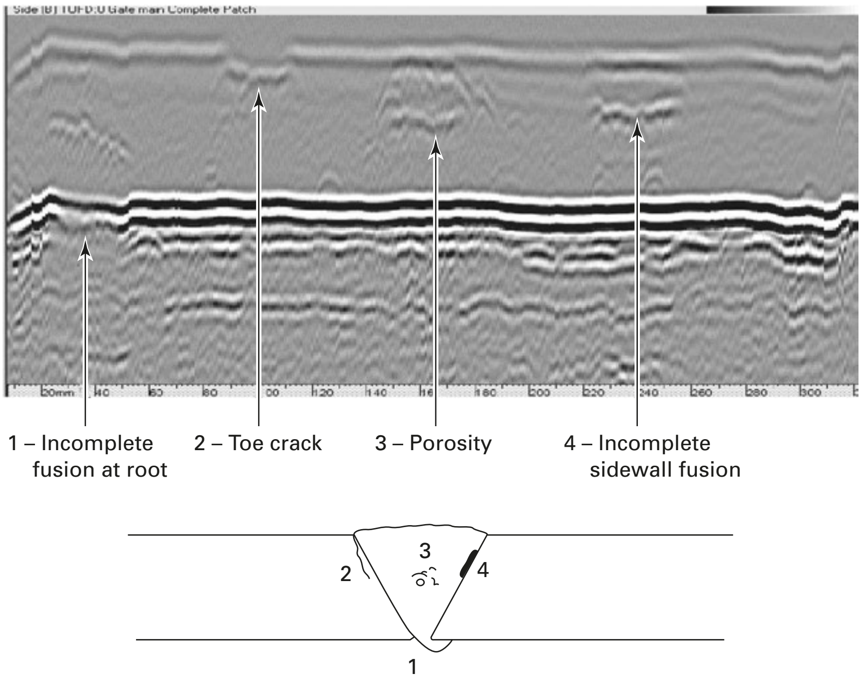
Figure N-482(a) Schematic of Flaw Locations and TOFD Image Showing the Lateral Wave, Backwall, and Three of the Four Flaws



GENERAL NOTES:

(a) Root crack (right): ~ 1.6 in. (40 mm) to 2.5 in. (64 mm) from one end.
(b) Incomplete sidewall fusion (mid-left): ~ 4 in. (100 mm) to 5 in. (125 mm).
(c) Slag: ~ 6.4 in. (163 mm) to 7.2 in. (183 mm).
(d) Incomplete fusion at root (left): ~ 9.3 in. (237 mm) to 10.5 in. (267 mm).

Figure N-482(b)
Schematic of Flaw Locations and TOFD Display Showing the Lateral Wave, Backwall, and Four Flaws



GENERAL NOTES:
(a) Incomplete fusion at root (left): ~ 0.6 in. (15 mm) to 1.8 in. (45 mm) from one end.
(b) Toe crack (top left): ~ 3 in. (80 mm) to 4 in. (100 mm).
(c) Porosity: ~ 5.5 in. (140 mm) to 6.25 in. (160 mm).
(d) Incomplete sidewall fusion (upper right): ~ 8 in. (200 mm) to 9.25 in. (235 mm).

N-483 TYPICAL PROBLEMS WITH TOFD INTERPRETATION

TOFD images can be corrupted by incorrect setups or other problems such as electrical noise. The following images were all made on the same plate to show some of the typical problems that can occur. Starting first with an acceptable scan, and then subsequent scans made to show various corruptions of this image.

(a) Acceptable Scan [Figure N-483(a)]. The gain and gate setting are reasonable, and the electrical noise is minimal.

(b) Incorrect Low Gain Setting [Figure N-483(b)]. The lateral wave and some of the diffracted signals are starting to disappear. At yet lower gain levels, some of the diffracted signals would become undetectable.

(c) Incorrect High Gain Setting [Figure N-483(c)]. The noise level increases to obscure the diffracted signals; this can lead to reduced probability of detection, and poor sizing. High noise levels can also arise from large grains. In this case, the solution is to reduce the ultrasonic frequency.

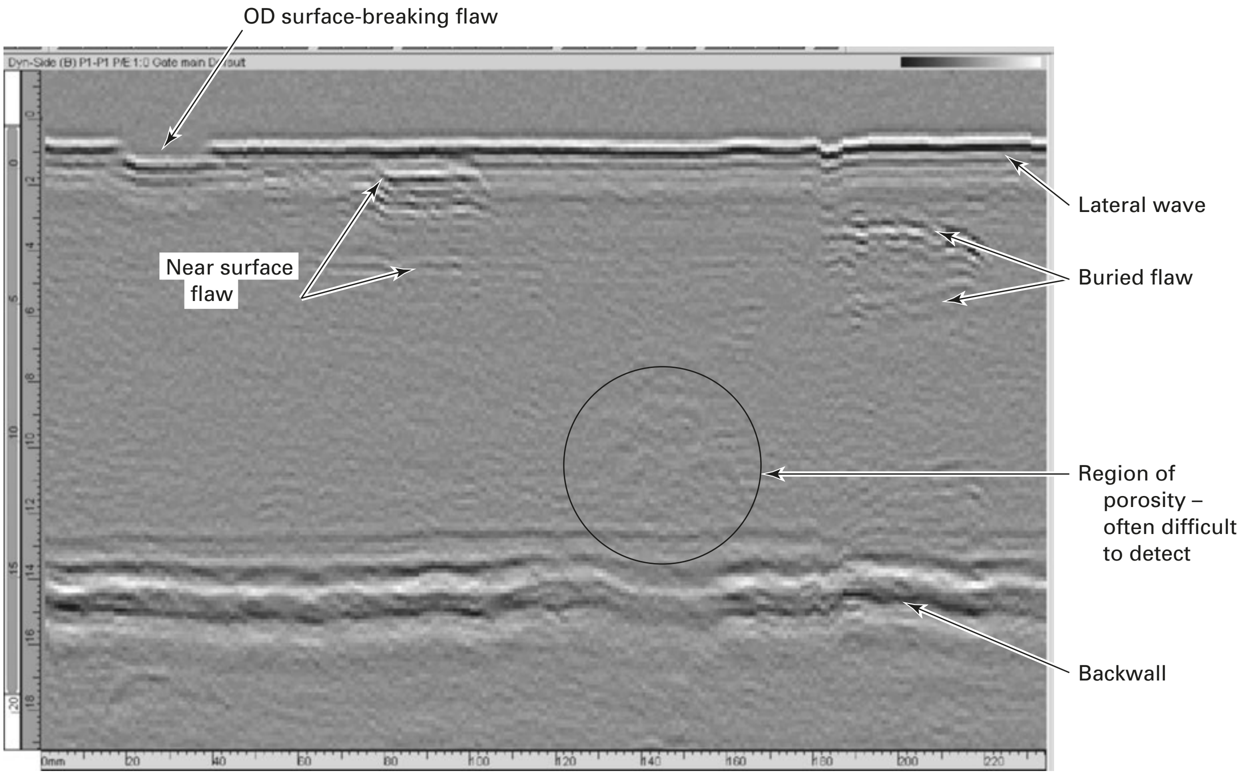
(d) Correct gate settings are critical, because TOFD A-scans are not that easy to interpret since there are multiple visible signals. As a minimum, the gates should encompass the lateral wave and longitudinal wave backwall signal; the gate can extend to the shear wave backwall, if required. Typically, the best signal to use as a guide is the first (longitudinal wave) backwall, since it is strong and always present (assuming the transducer separation is reasonably correct). The following figures show examples of incorrect gate positioning, which will inherently lead to poor flaw detection.

The first example, Figure N-483(d)(1), shows the gate set too early, the lateral wave is visible, and the backwall is not. Any inside (I.D.) near-backwall flaws will be missed.

The second example, Figure N-483(d)(2), shows the gate set too late. The lateral wave is not visible. The first signal is the backwall, and the second signal is the shear wave backwall. With this setup, all the outside (O.D.) near-surface flaws will be missed.

The third example, Figure N-483(d)(3), is with the gate set too long. Though this is not technically incorrect, the image will show the diffracted backwall shear-shear wave signal. These S-S waves may show additional and confirmatory information. The diffracted shear waves show the porosity more clearly than the diffracted longitudinal waves and there is a strong mode-converted signal that

Figure N-483(a)
Acceptable Noise Levels, Flaws, Lateral Wave, and Longitudinal Wave Backwall



occurs just before the shear wave gate, which could cause interpretation problems. Normally, the gate is set fairly short to enclose only the lateral wave and the longitudinal wave backwall to clarify interpretation.

(e) Incorrect (too far apart) transducer separation [Figure N-483(e)] results in the backwall signal becoming distorted, the lateral wave becomes weaker, and some of the diffracted signal amplitudes drop.

(f) Incorrect (too close together) transducer separation [Figure N-483(f)] results in the lateral waves becoming stronger, and the backwall weaker. Again, the TOFD image of the flaws is poor.

(g) If the transducers are not centered on the weld [Figure N-483(g)], the diffracted signal amplitudes will decline to the point where flaw detection is seriously impaired.

(h) Noise levels [Figure N-483(h)] can seriously impair TOFD interpretation. Noise can come from a number of sources such as electrical, ultrasonic, grains, and coupling. Typically, ultrasonic and grain noise appears universally across the TOFD image. Electrical noise appears as an interference pattern, depending on the noise source. Once the occurrence of the electrical noise increases beyond a certain point, interpretation becomes essentially impossible.

Figure N-483(b)
TOFD Image With Gain Too Low

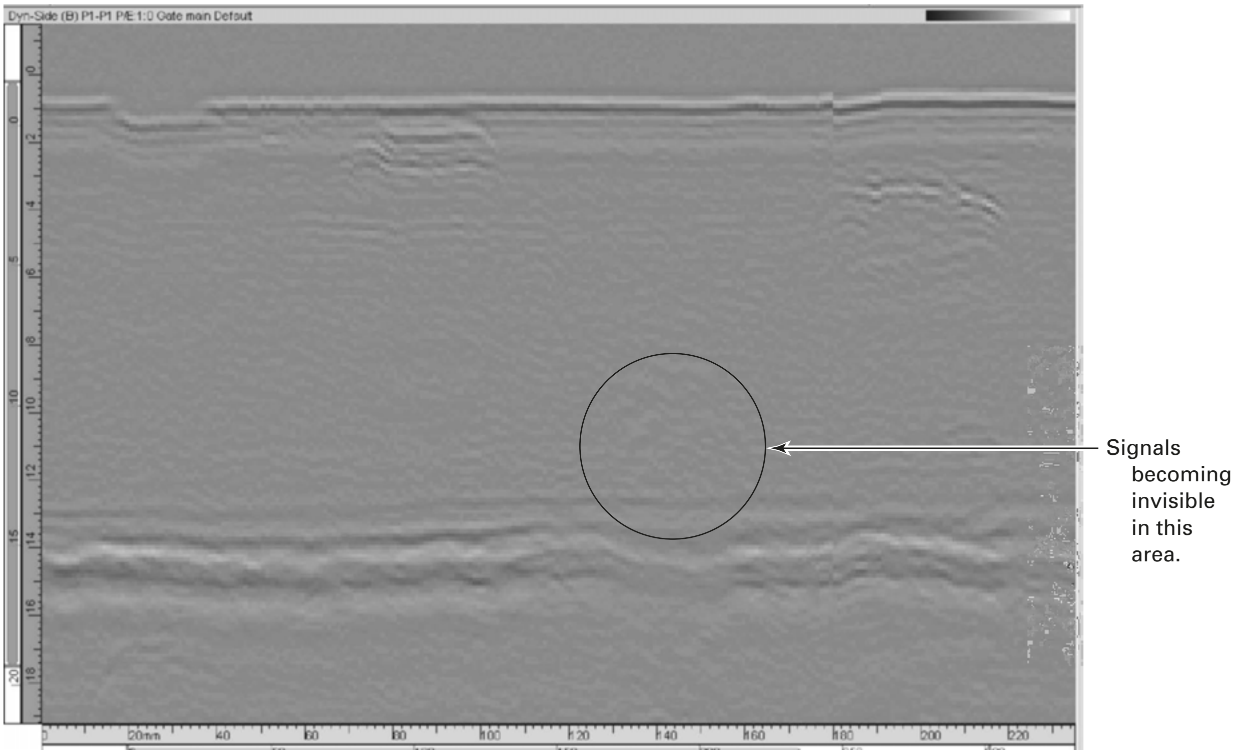


Figure N-483(c)
TOFD Image With Gain Set Too High

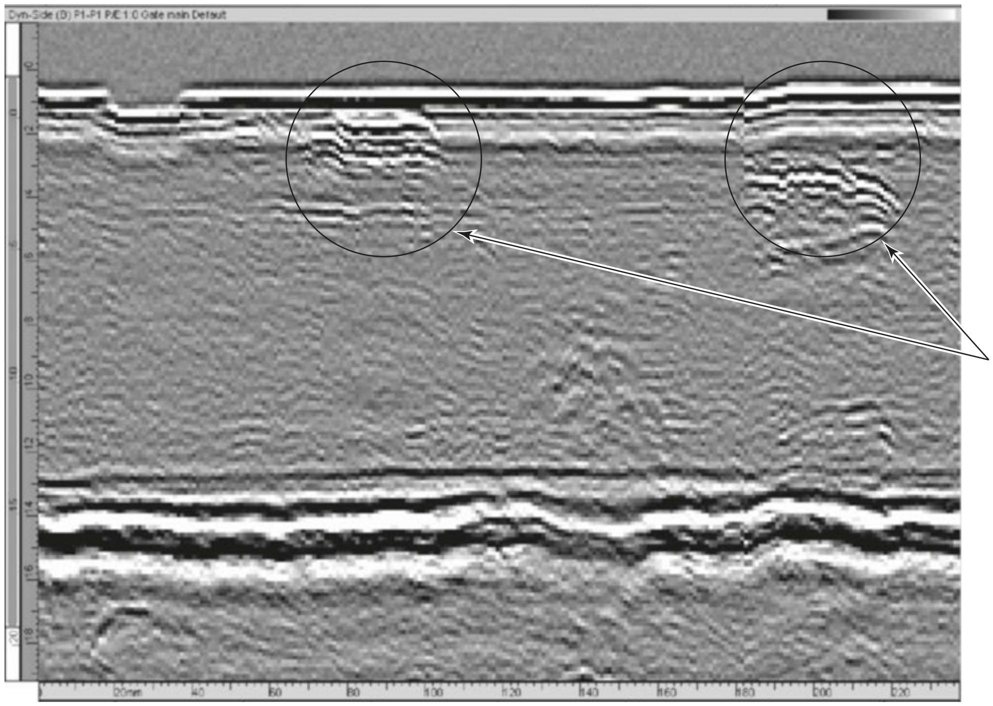


Figure N-483(d)(1)
TOFD Image With the Gate Set Too Early

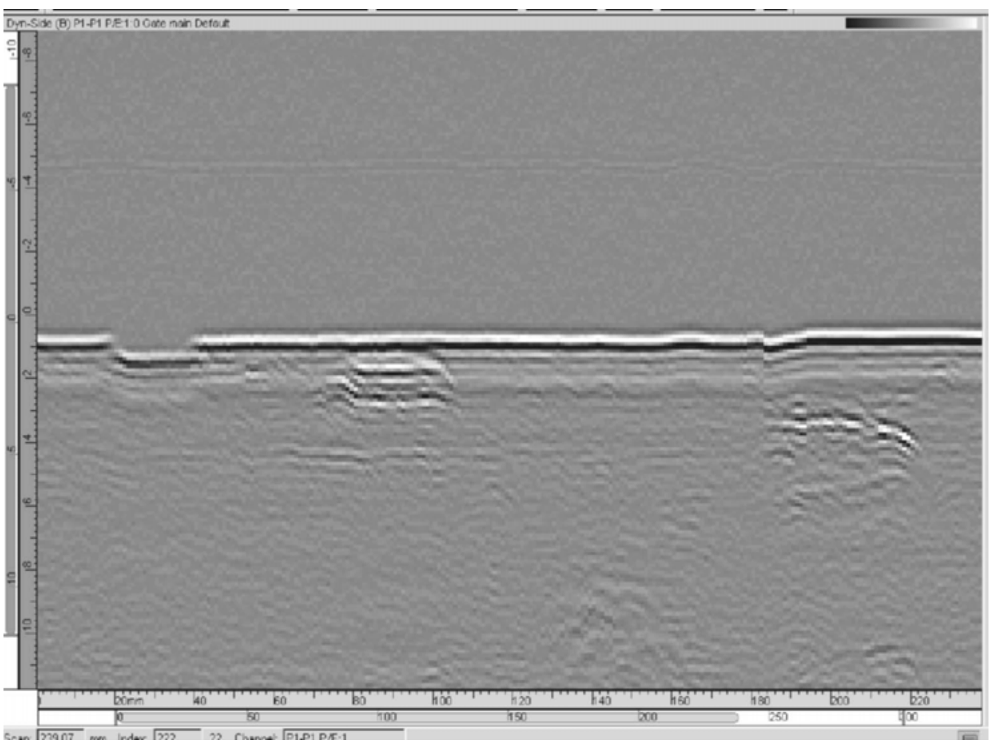


Figure N-483(d)(2)
TOFD Image With the Gate Set Too Late

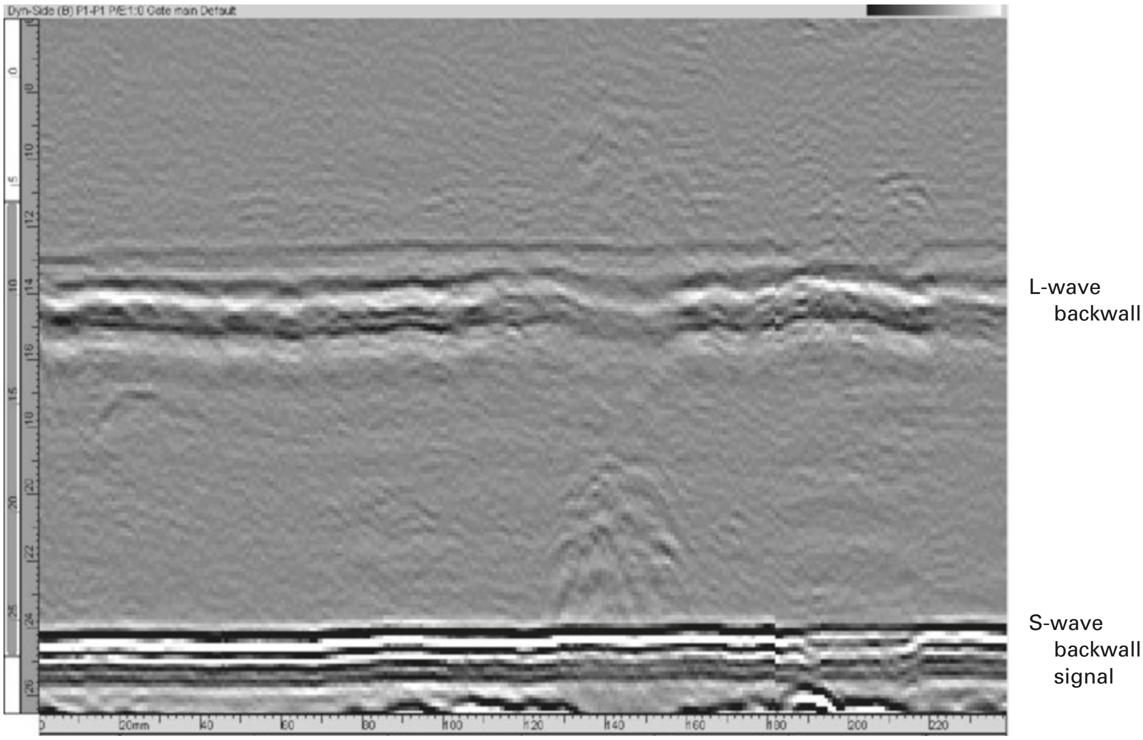


Figure N-483(d)(3)
TOFD Image With the Gate Set Too Long

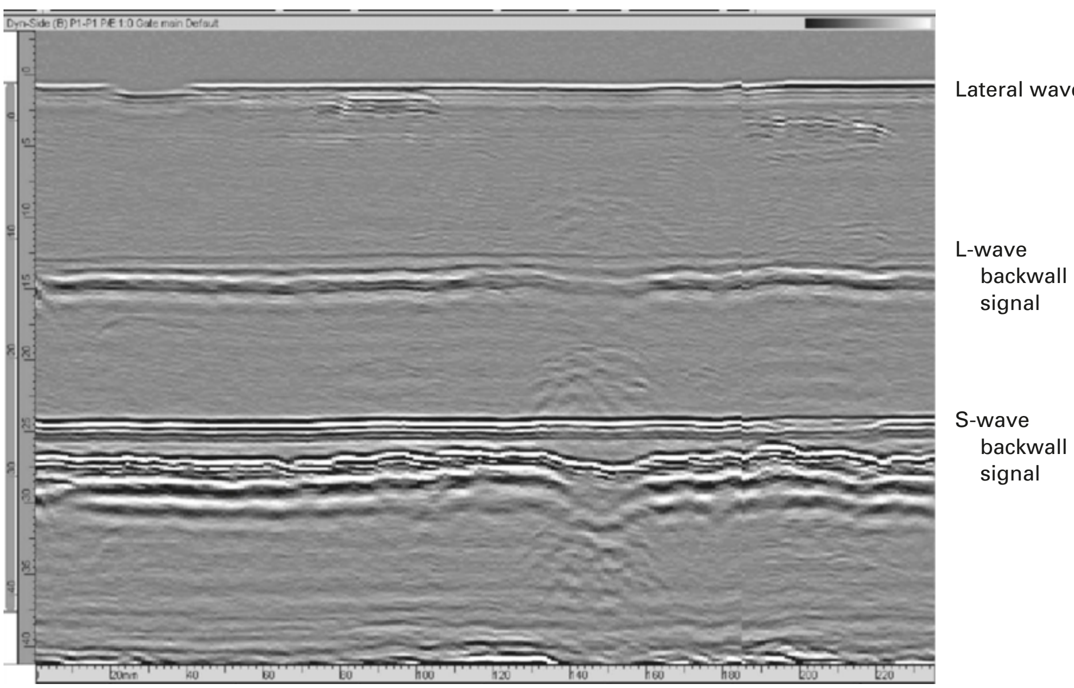


Figure N-483(e)
TOFD Image With Transducers Set Too Far Apart

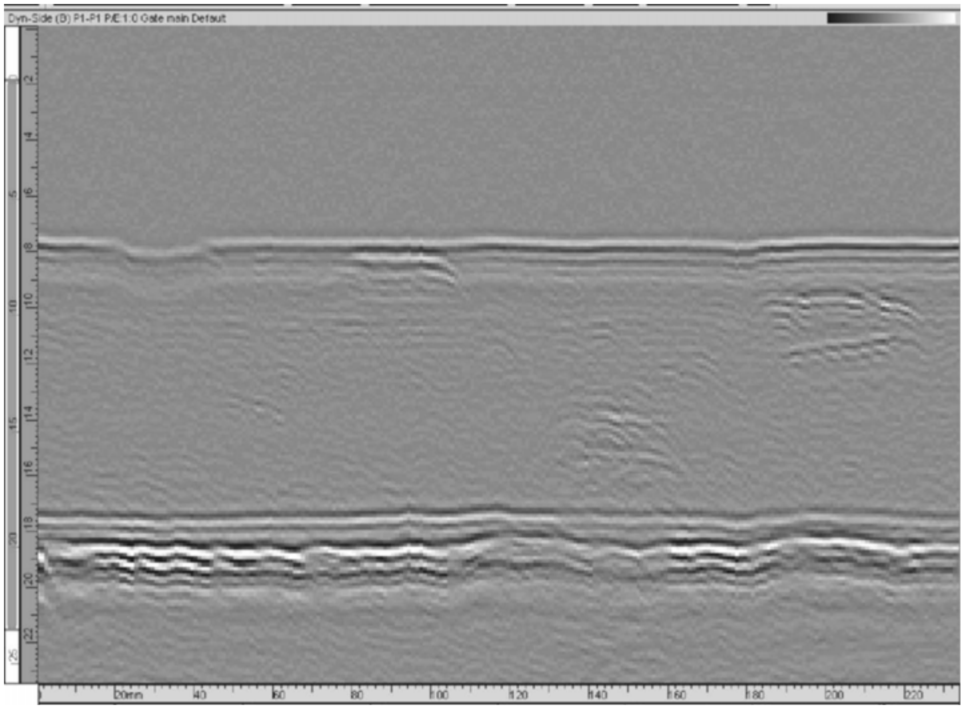


Figure N-483(f)
TOFD Image With Transducers Set Too Close Together

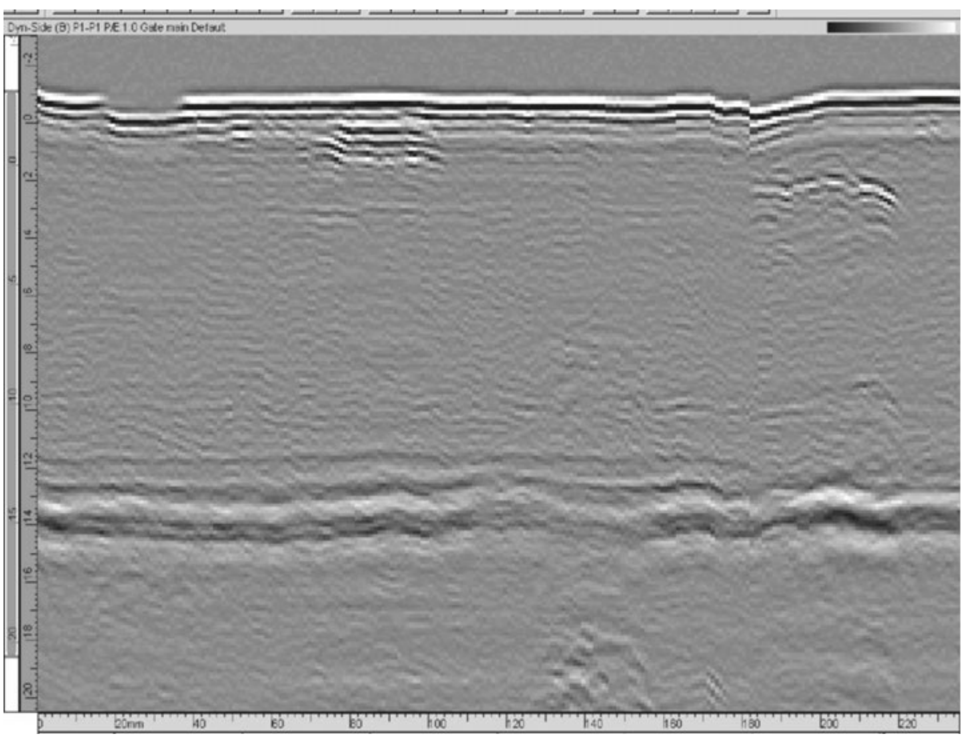


Figure N-483(g)
TOFD Image With Transducers Not Centered on the Weld Axis

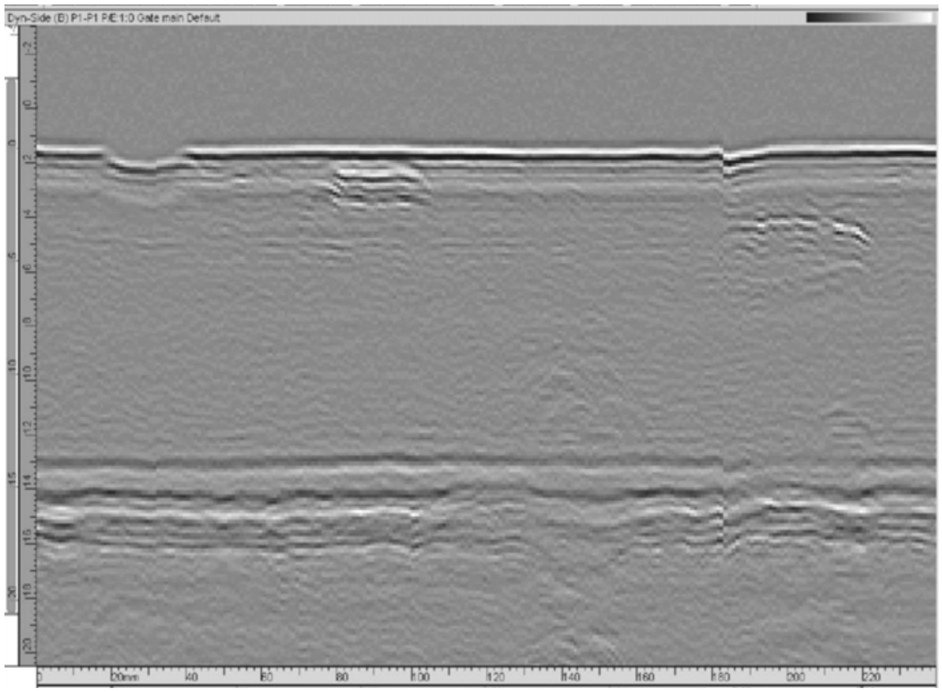
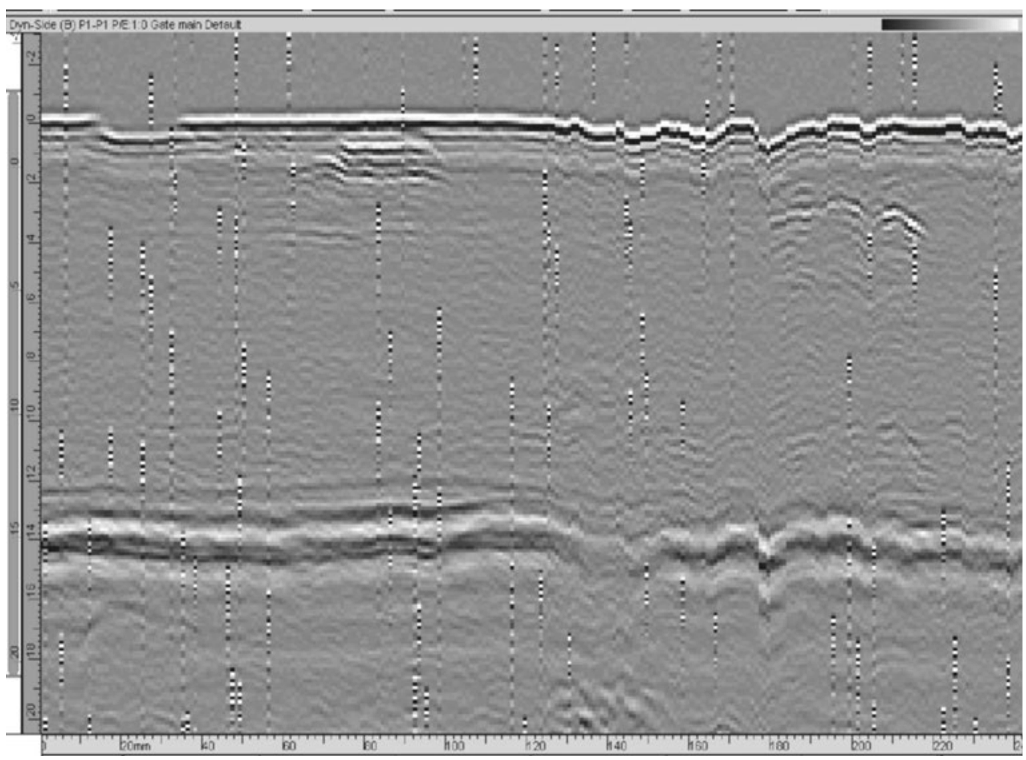


Figure N-483(h)
TOFD Image Showing Electrical Noise Interference



NONMANDATORY APPENDIX O
TIME OF FLIGHT DIFFRACTION (TOFD) TECHNIQUE — GENERAL EXAMINATION CONFIGURATIONS

O-410 SCOPE

This Appendix describes general weld examination configurations for the Time of Flight Diffraction (TOFD) technique.

O-430 EQUIPMENT

O-432 SEARCH UNITS

Tables O-432(a) and O-432(b) provide general search unit parameters for specified thickness ranges in ferritic welds. For austenitic or other high attenuation materials, see T-451.

Table O-432(a)
Search Unit Parameters for Single Zone Examinations Up to 3 in. (75 mm)

Thickness, t, in. (mm)	Nominal Frequency, MHz	Element Size, in. (mm)	Angle, deg
< 0.5 (< 13)	10 to 15	0.125 to 0.25 (3 to 6)	60 to 70
0.5 to < 1.5 (13 to < 38)	5 to 10	0.125 to 0.25 (3 to 6)	50 to 70
1.5 to < 3 (38 to < 75)	2 to 5	0.25 to 0.5 (6 to 13)	45 to 65

Table O-432(b)
Search Unit Parameters for Multiple Zone Examinations Up to 12 in. (300 mm) Thick

Nominal Wall, in. (mm)	Nominal Frequency, MHz	Element Size, in. (mm)	Angle, deg
< 1.5 (< 38)	5 to 15	0.125 to 0.25 (3 to 6)	50 to 70
1.5 to 12 (38 to 300)	1 to 5	0.25 to 0.5 (6 to 12.5)	45 to 65

O-470 EXAMINATION

For thicknesses approaching 3 in. (75 mm), the beam divergence from a single search unit is not likely to provide sufficient intensity for good detection over the entire examination volume. Therefore, for thickness 3 in. (75 mm) and greater, the examination volume should be divided into multiple zones. Table O-470 provides general guidance on the number of zones to ensure suitable volume coverage.

Examples of the search unit layout and approximate beam volume coverage are provided in Figure O-470(a) through Figure O-470(d).

Table O-470
Recommended TOFD Zones for Butt Welds Up to 12 in. (300 mm) Thick

Thickness, t, in. (mm)	Number of Zones [Note (1)]	Depth Range	Beam Intersection (Approx.)
< 2 (< 50)	1	0 to t	$^2/_3t$
2 to < 4 (50 to < 100)	2	0 to $^1/_2t$ $^1/_2t$ to t	$^1/_3t$ $^5/_6t$
4 to < 8 (100 to < 200)	3	0 to $^1/_3t$ $^1/_3t$ to $^2/_3t$ $^2/_3t$ to t	$^2/_9t$ $^5/_9t$ $^8/_9t$
8 to 12 (200 to 300)	4	0 to $^1/_4t$ $^1/_4t$ to $^1/_2t$ $^1/_2t$ to $^3/_4t$ $^3/_4t$ to t	$^1/_6t$ $^5/_{12}t$ $^2/_3t$ $^{11}/_{12}t$

NOTE:
(1) Multiple zones do not have to be of equal height.

Figure O-470(a)
Example of a Single Zone TOFD Setup

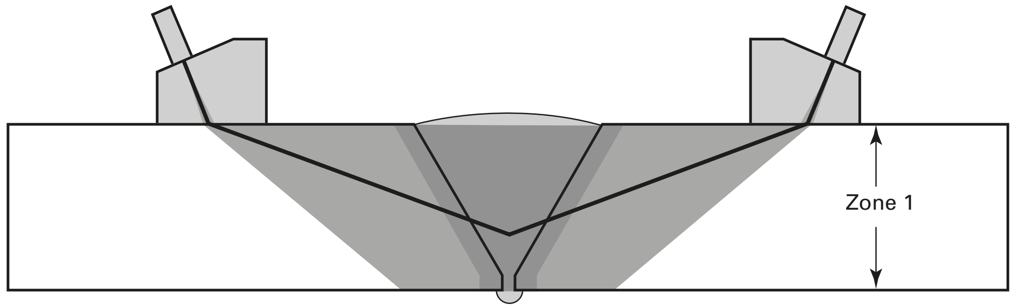


Figure O-470(b)
Example of a Two Zone TOFD Setup (Equal Zone Heights)

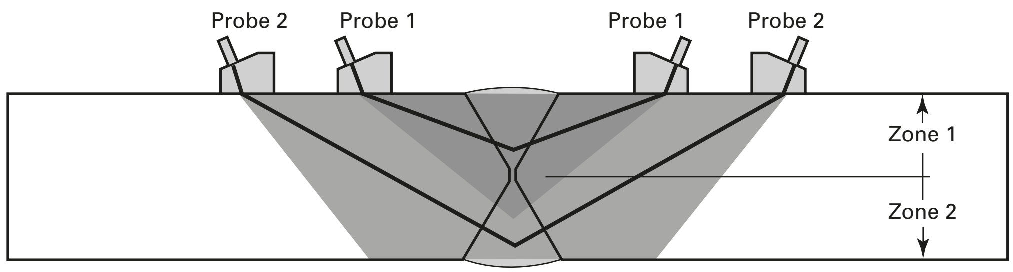


Figure O-470(c)
Example of a Three Zone TOFD Setup (Unequal Zone Heights With Zone 3 Addressed by Two Offset Scans)

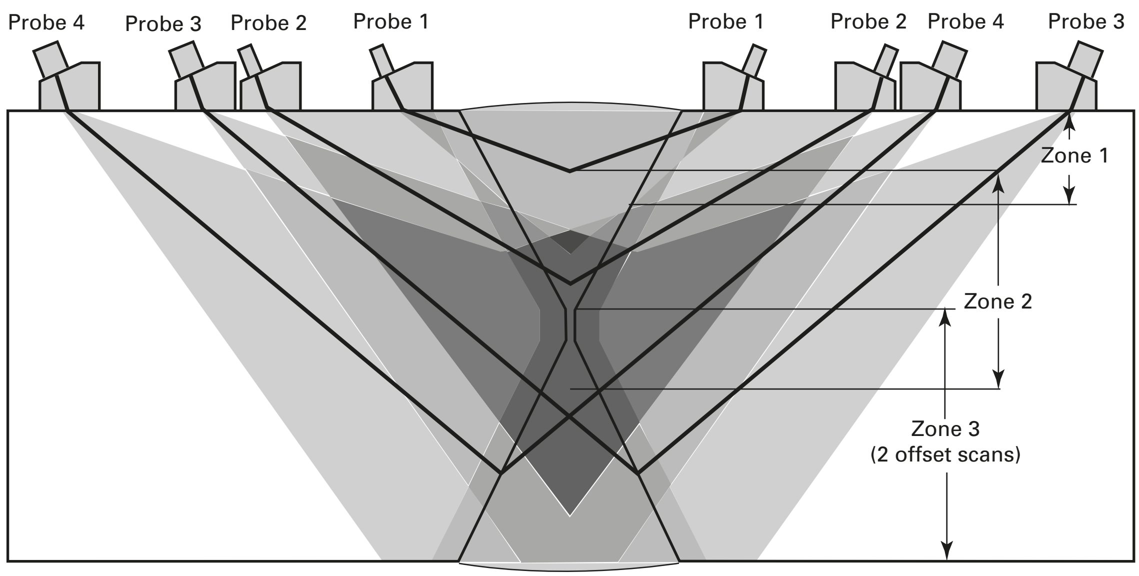
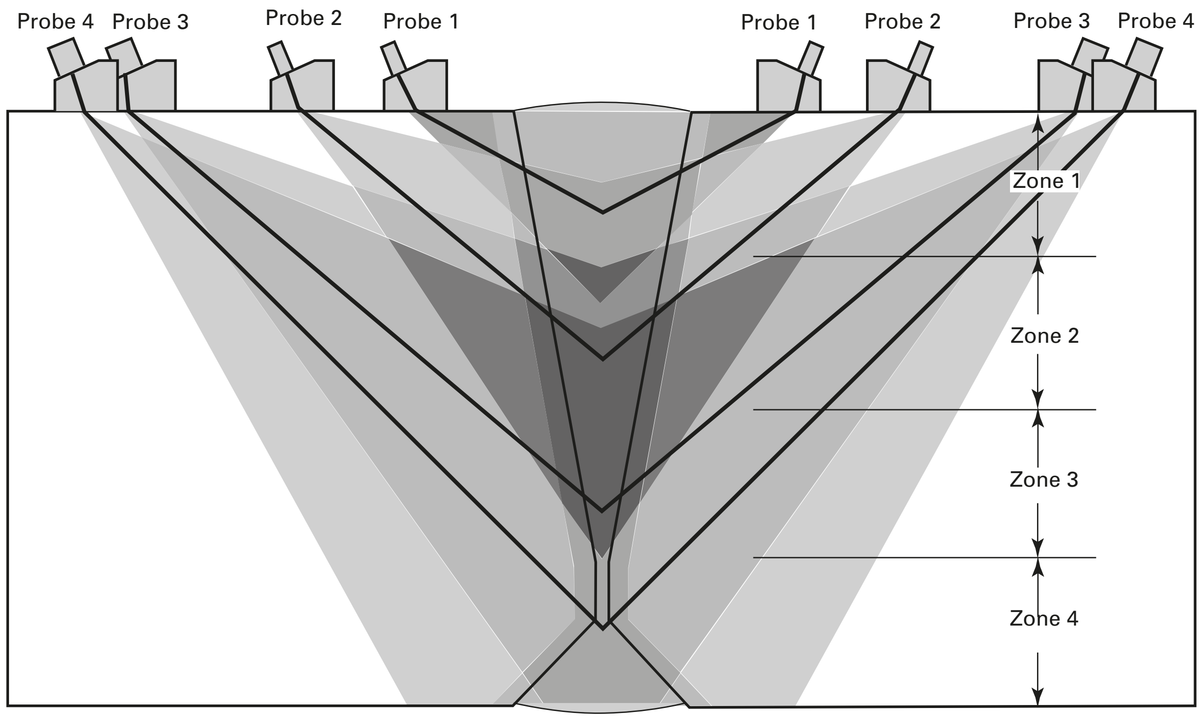


Figure O-470(d)
Example of a Four Zone TOFD Setup (Equal Zone Heights)



NONMANDATORY APPENDIX P
PHASED ARRAY (PAUT) INTERPRETATION

P-410 SCOPE

This Nonmandatory Appendix is to be used as an aid for the interpretation of Phased Array Ultrasonic Testing (PAUT) images.[19] The flaw signal interpretation methodology using PAUT is very similar to that of conventional ultrasonics; however, PAUT has improved imaging capabilities that aid in flaw signal interpretation. This interpretation guide is primarily aimed at using shear wave angle beams on butt welds. Other possibilities include

(a) longitudinal waves

(b) zero degree scanning

(c) complex inspections, e.g., nozzles, fillet welds

P-420 GENERAL

P-421 PAUT IMAGES — DATA VISUALIZATION

PAUT data is routinely displayed using a rainbow color palette, with the range of colors representing a range of signal amplitude. Generally, "white" represents 0% signal amplitude, "blue" (or lighter colors) represents low amplitudes, and "red" (or darker colors) represents above reject signal amplitude (see Figure P-421-1).

(a) PAUT has the ability to image the data in the same format as conventional ultrasonics – A-scans, and time or distance encoded B-scan, D-scan, and C-scans. (See Figure P-421-2.)

NOTE: The examples shown here are not necessarily typical of all defects due to differences in shape, size, defect orientation, roughness, etc.

(b) The PAUT primary image displays are an E-scan or S-scan, exclusive to the PAUT technique. Both the E-scan and S-scan display the data in a 2D view, with distance from the front of the wedge on the X-axis, and depth on the Y-axis. This view is also considered an "end view." E-scans and S-scans are composed of all of the A-scans (or focal laws) in a particular setup. The A-scan for each beam (or focal law) is available for use in flaw signal interpretation.

(c) An E-scan (also termed an electronic raster scan) is a single focal law multiplexed, across a group of active elements, for a constant angle beam stepped along the phased array probe length in defined increments. Figure P-421-3 shows an example of an E-scan.

(d) An S-scan (also termed a Sector, Sectorial, Swept Angle, or Azimuthal scan) may refer to either the beam movement or the data display (see Figure P-421-4).

P-450 PROCEDURE

P-451 MEASUREMENT TOOLS

PAUT instruments typically have flaw sizing aids contained within the software. These sizing aids are based on using multiple sets of horizontal and vertical cursors overlaid on the various image displays. PAUT instruments rely on the accuracy of the user input information (such as component thickness) and calibration to accurately display flaw measurements and locations.

P-452 FLAW SIZING TECHNIQUES

Flaw sizing can be performed using a variety of industry accepted techniques, such as amplitude drop (e.g., -6 dB Drop) techniques and/or tip diffraction techniques. Different flaw types may require different sizing techniques.

P-452.1 Flaw Length. Flaw lengths parallel to the surface can be measured from the distance encoded D- or C-scan images using amplitude drop techniques by placing the vertical cursors on the extents of the flaw displayed on the D- or C-scan display. Figure P-452.1 shows an example of cursors used for length sizing.

P-452.2 Flaw Height. Flaw height normal to the surface can be measured from the B-, E-, or S-scan images using amplitude drop or tip diffraction techniques.

(a) Using amplitude drop techniques, the horizontal cursors are placed on the displayed flaws upper and lower extents. Figure P-452.2-1 shows an example of cursors used for height sizing with the amplitude drop technique.

(b) Using tip diffraction techniques the horizontal cursors are placed on the upper and lower tip signals of the displayed flaw. Figure P-452.2-2 shows an example of cursors used for height sizing with the tip diffraction technique.

P-480 EVALUATION

This section shows a variety of PAUT images and the interpretation/explanation. There are significant variations amongst flaws and PAUT setups and displays, so the following images should be used as a guide only. Evaluator experience and analysis skills are very important as well.

P-481 I.D. (INSIDE DIAMETER) CONNECTED CRACK

These typically show multiple facets and edges visible in the A-scan and S-scan. There is a distinct start and stop on the A-scan, and a significant echodynamic travel to the signal as the probe is moved in and out from the weld (if the crack has significant vertical extent). The reflector is usually detectable and can be plotted from both sides of the weld. The reflector should plot to the correct I.D. depth reference or depth reading, as shown in Figure P-481.

P-481.1 Lack of Sidewall Fusion. LOF (Lack of Fusion) plots correctly on the weld fusion line, either through geometrical plotting or via weld overlays. There may be a significantly different response from each side of the weld. LOF is usually detected by several of the angles in an S-scan from the same position. The A-scan shows a fast rise and fall time with short pulse duration indicative of a planar flaw. There are no multiple facets or tips.

Skewing the probe slightly does not produce multiple peaks or jagged facets as in a crack. There may be mode-converted multiple signals that rise and fall together and maintain equal separation. Figure P-481.1 shows an example.

P-481.2 Porosity. Porosity shows multiple signal responses, varying in amplitude and position. The signals plot correctly to the weld volume. The signals' start and stop positions blend with the background at low amplitude. The A-scan slow rise and fall time with long pulse duration is indicative of a nonplanar flaw. Porosity may or may not be detected from both sides of the weld, but should be similar from both sides. Figure P-481.2 shows an example of porosity.

P-481.3 O.D. (Outside Diameter) Toe Crack. Toe cracks typically show multiple facets and edges visible in the A-scan and S-scan. There is significant echodynamic travel to the signal as the probe is moved in and out from the weld. The reflector is usually detectable and can be plotted from at the correct O.D. depth reference line or depth reading. Normally, toe cracks are best characterized on S-scans and lower angle E-scan channels. Figure P-481.3 shows an example.

P-481.4 (Incomplete Penetration). Incomplete Penetration (IP) typically shows high amplitude signals with significant echodynamic travel or travel over the I.D. skip line. IP will typically respond and plot from both sides of the weld in common weld geometries near centerline reference indicators. Generally, IP is detected on all channels, with highest amplitude on a high angle E-scan. The A-scan shows a fast rise and fall time with short pulse duration indicative of a planar flaw. Figure P-481.4 shows an IP signal.

Note that IP must be addressed relative to the weld bevel. For example, a double V weld will have IP in the midwall, whereas a single V bevel will be surface-breaking. However, the rise-fall time of the signal is similar to that for toe cracks and other root defects. This requires extra care on the part of the operator. Note that incomplete penetration can look similar to surface lack of sidewall fusion.

P-481.5 Slag. Slag typically shows multiple facets and edges visible in the A-scan and S-scan. The A-scan shows a slow rise and fall time with long pulse duration, indicative of a nonplanar flaw. Typically slag shows lower amplitude than planar flaws, and may be difficult to distinguish from porosity, or from some smaller planar defects. Slag is typically detectable from both sides, can be plotted from both sides of the weld and is often best characterized using an S-scan. A slag reflector will typically plot to the correct depth area and reference lines that coincide to the weld volume. Figure P-481.5 shows an example.

Figure P-421-1
Black and White (B&W) Version of Color Palette

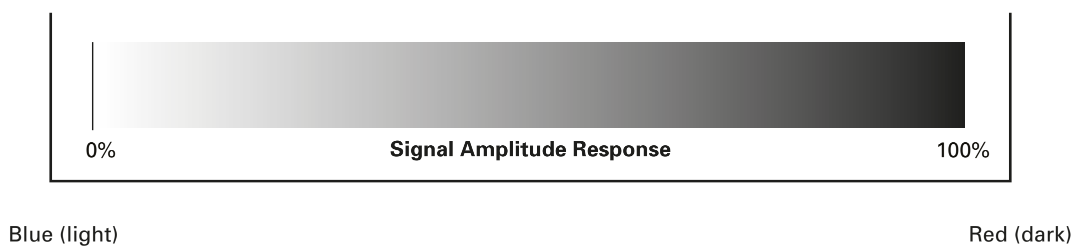


**Figure P-421-2
Scan Pattern Format**

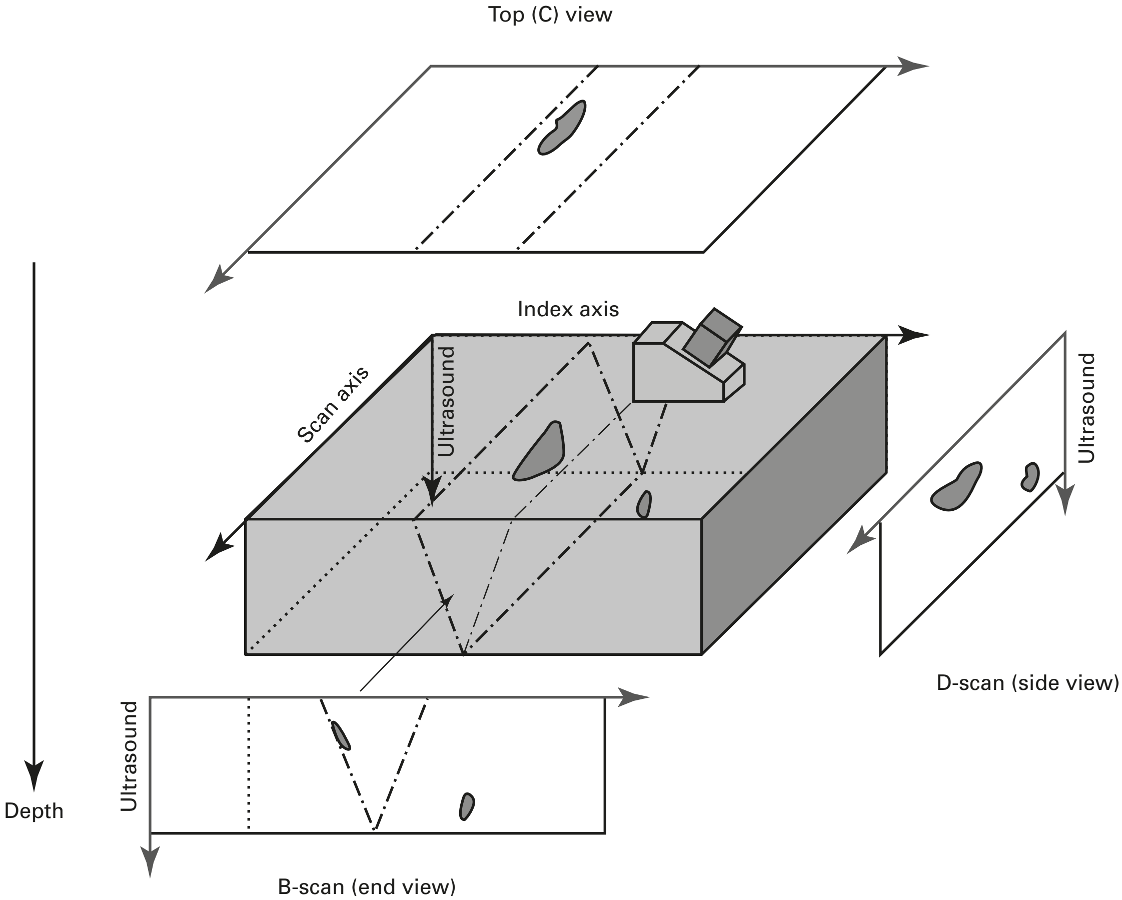


Figure P-421-3
Example of an E-Scan Image Display

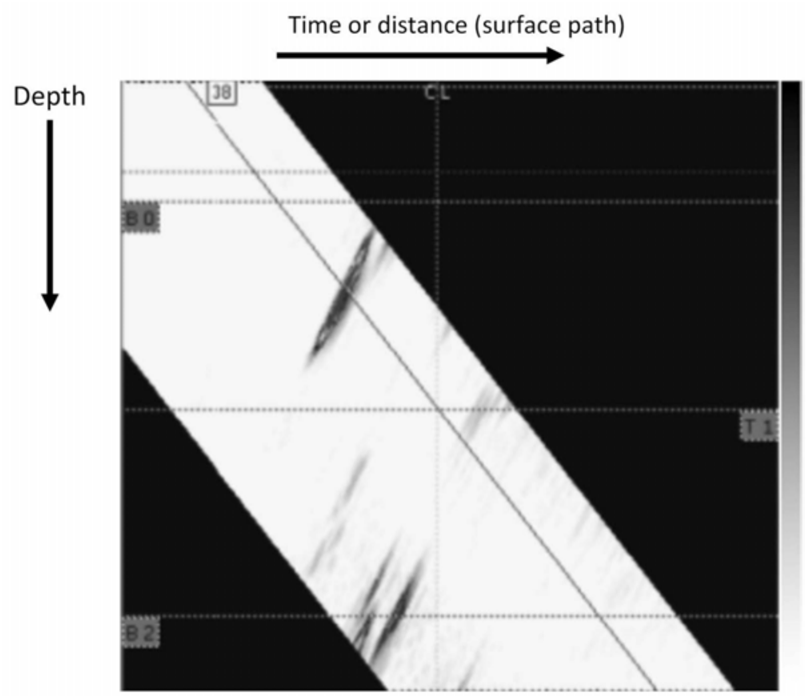


Figure P-421-4
Example of an S-Scan Image Display

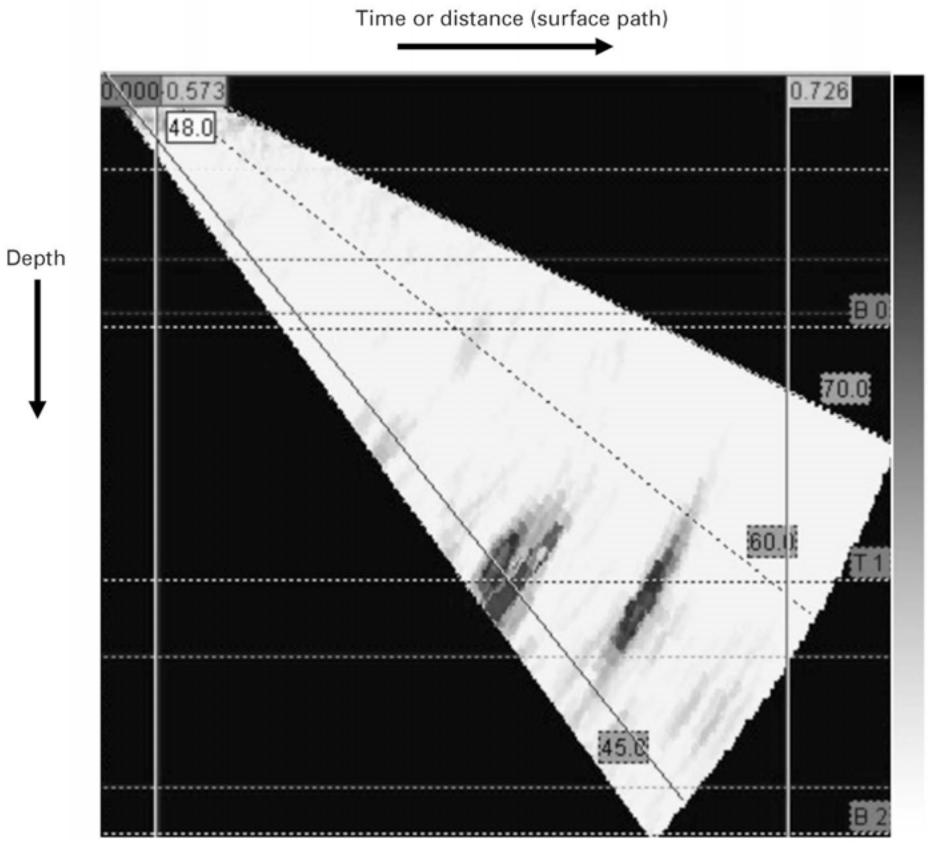


Figure P-452.1
Flaw Length Sizing Using Amplitude Drop Technique and the Vertical Cursors on the C-Scan Display

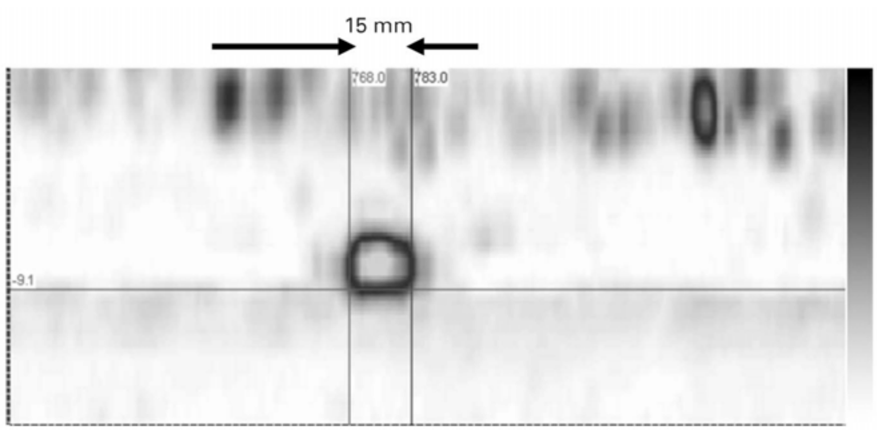


Figure P-452.2-1
Scan Showing Flaw Height Sizing Using Amplitude Drop Technique and the Horizontal Cursors on the B-Scan Display

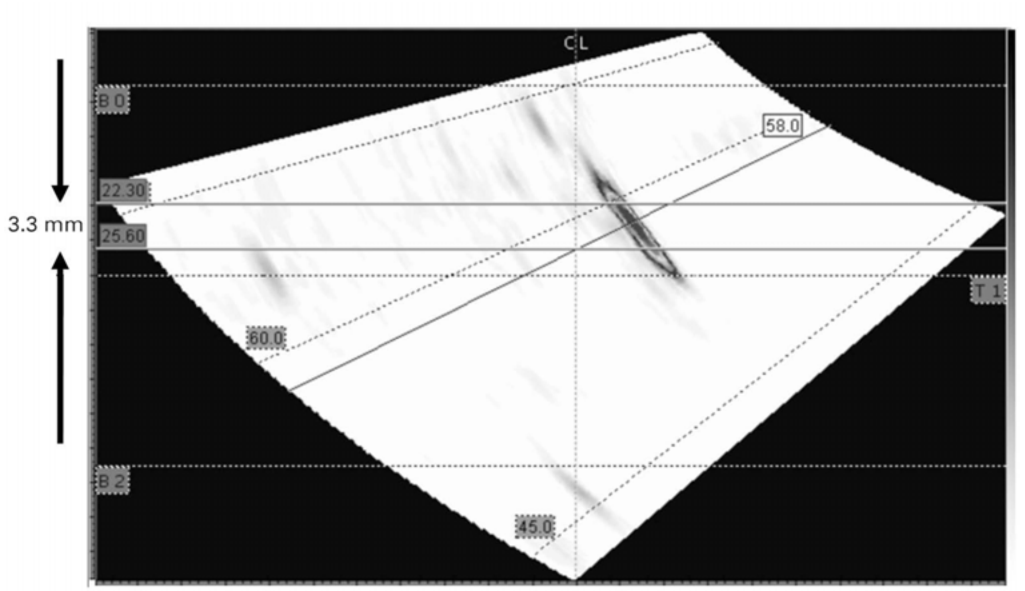
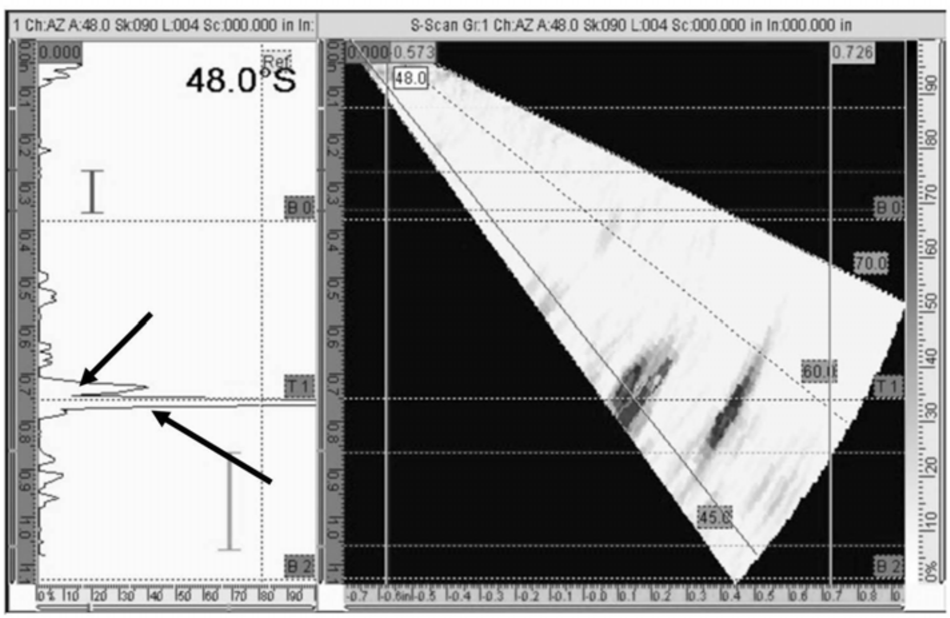


Figure P-452.2-2
Flaw Height Sizing Using Top Diffraction Technique and the Horizontal Cursors on the S-Scan Display



GENERAL NOTE: The two arrows in the A-scan at left show the relevant signals for measurement.

Figure P-481
S-Scan of I.D. Connected Crack

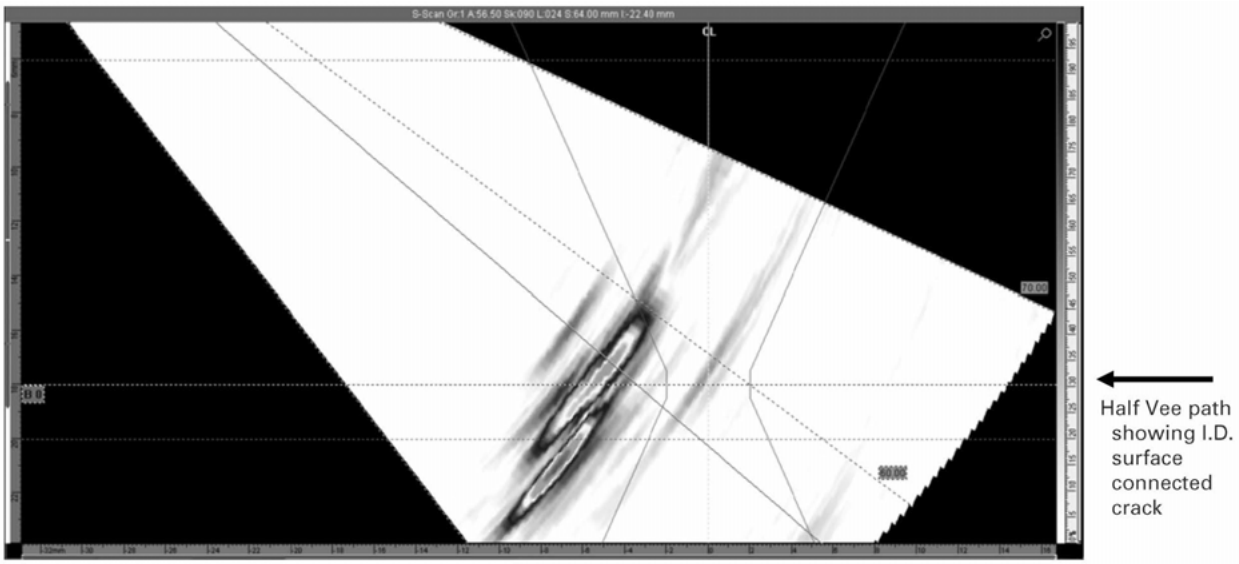


Figure P-481.1
E-Scan of LOF in Midwall

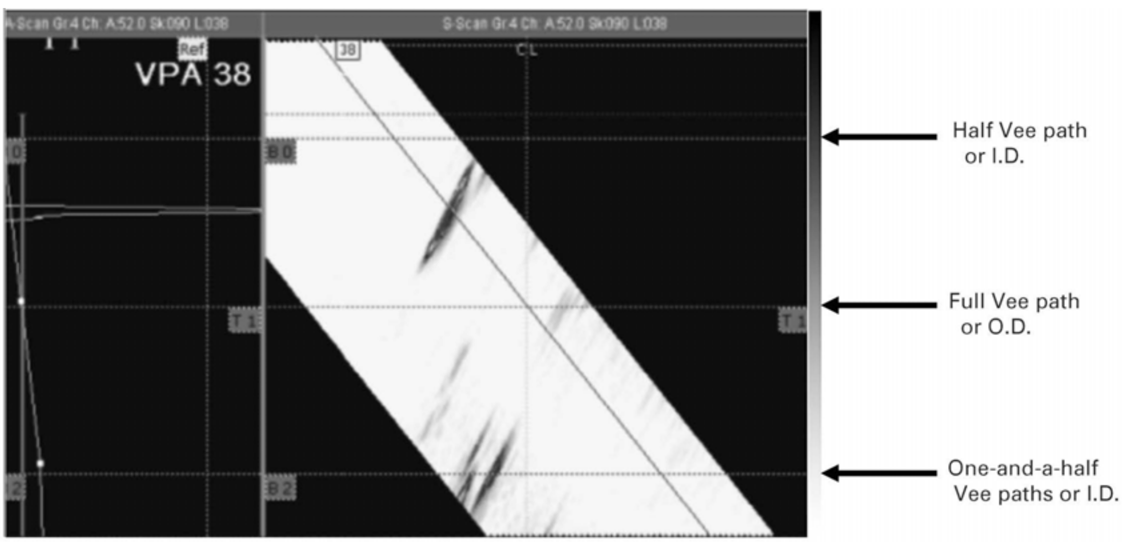


Figure P-481.2
S-Scan of Porosity, Showing Multiple Reflectors

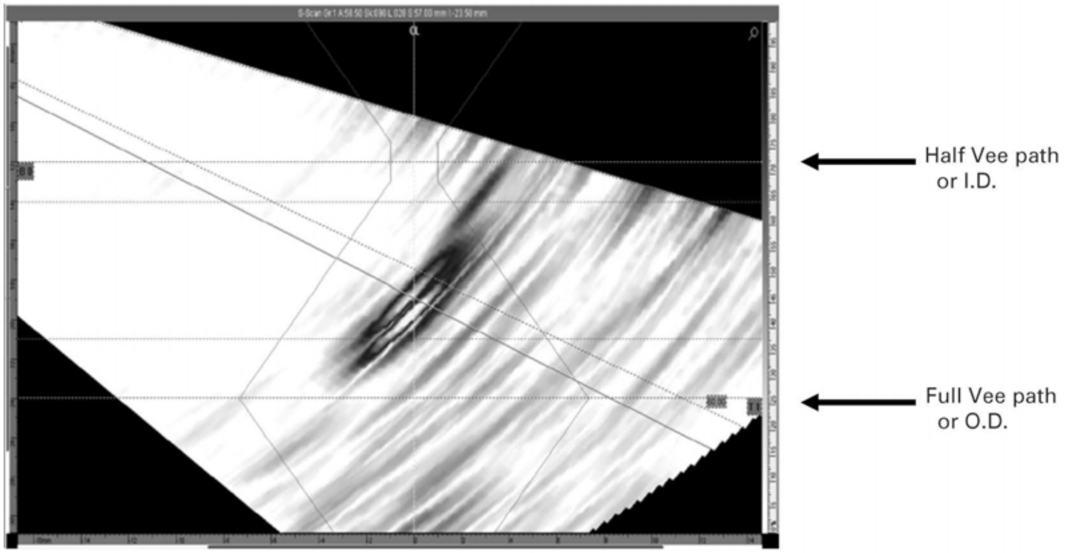


Figure P-481.3
O.D. Toe Crack Detected Using S-Scan

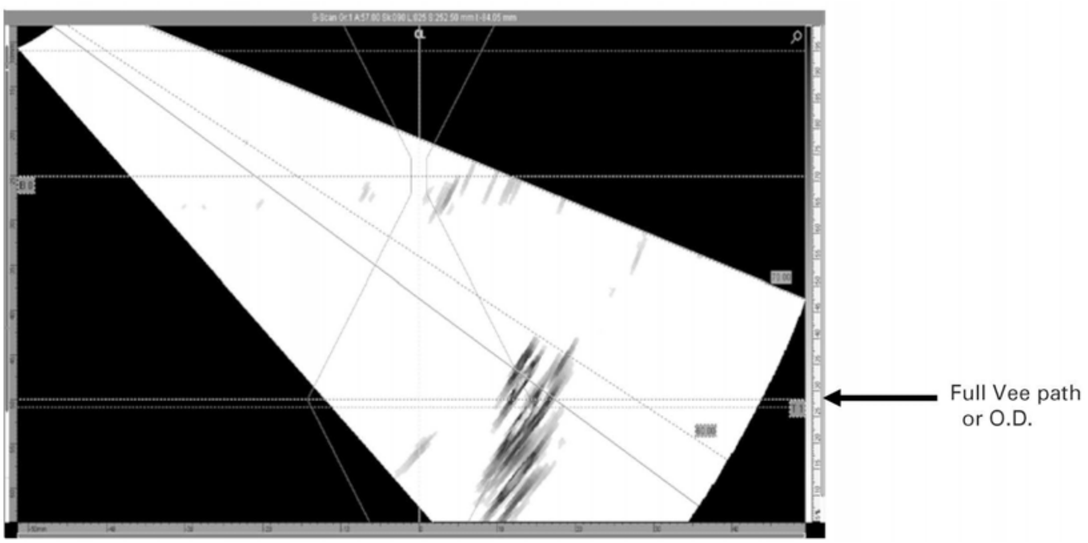


Figure P-481.4
IP Signal on S-Scan, Positioned on Root

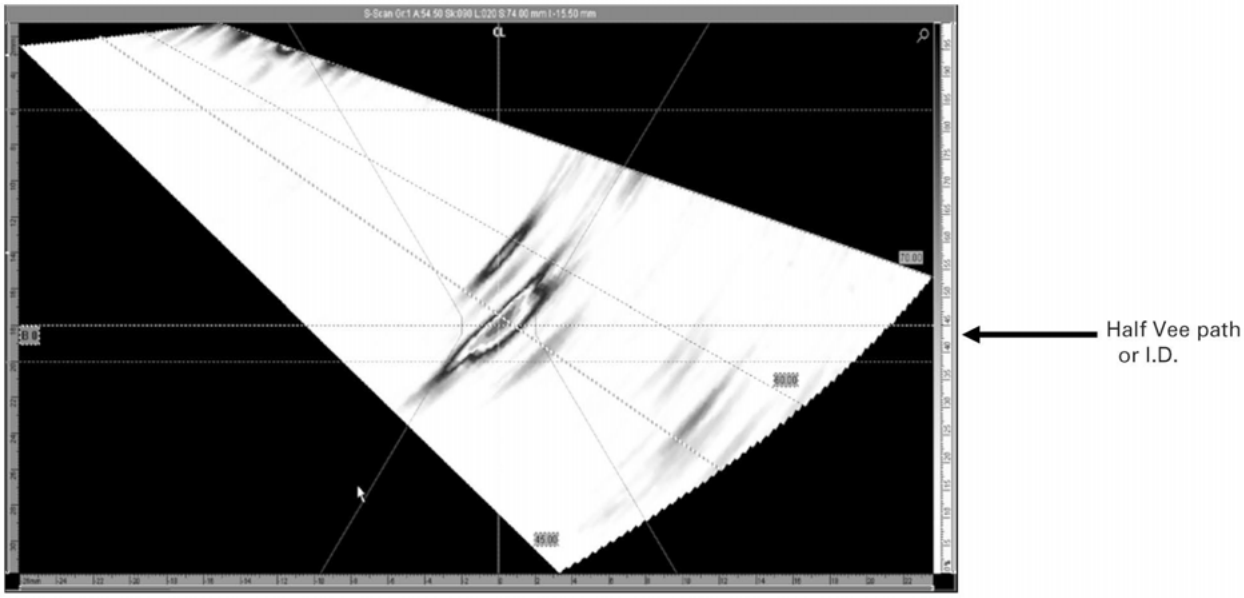
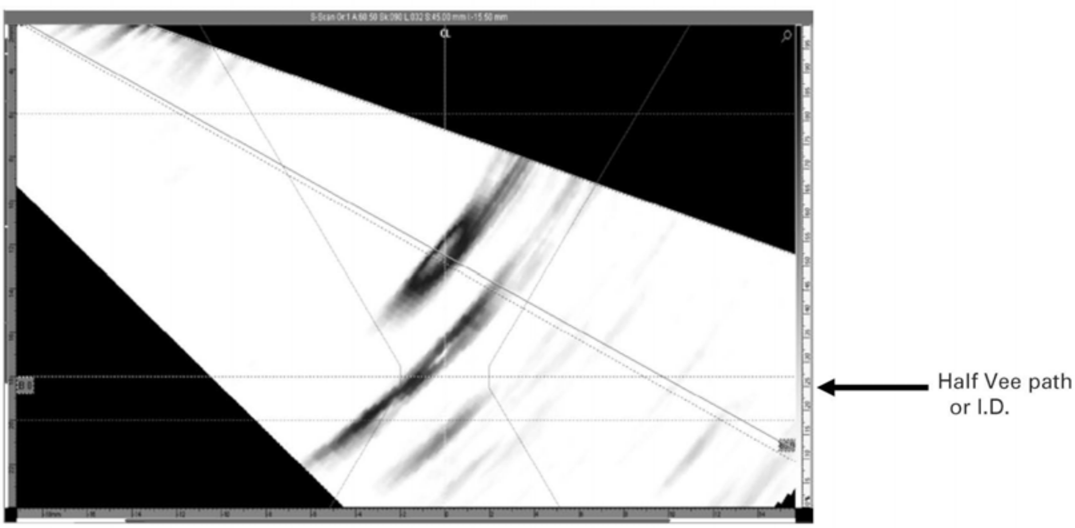


Figure P-481.5
Slag Displayed as a Midwall Defect on S-Scan



NONMANDATORY APPENDIX Q
EXAMPLE OF A SPLIT DAC CURVE

Q-410 SCOPE

This Appendix provides an example of a split DAC curve when a single DAC curve, for the required distance range, would have a portion of the DAC fall below 20% of full screen height (FSH). See Figure Q-410.

Q-420 GENERAL

Q-421 FIRST DAC

Create a DAC curve as normal until a side-drilled hole (SDH) indication peak signal falls below 20% of FSH. See Figure Q-421.

Q-422 SECOND DAC

Starting with a SDH position prior to the reflector response that falls below 20% of FSH, set the gain so that this response is 80% ± 5% of FSH. Record the reference level gain setting for this second portion of the DAC curve. Mark the peaks of the remaining SDH indications on the screen and connect the points to form the second DAC curve. See Figure Q-422.

Q-423 NOTCH REFLECTORS

This technique can also be used for notch reflectors.

Figure Q-410
Distance–Amplitude Correction

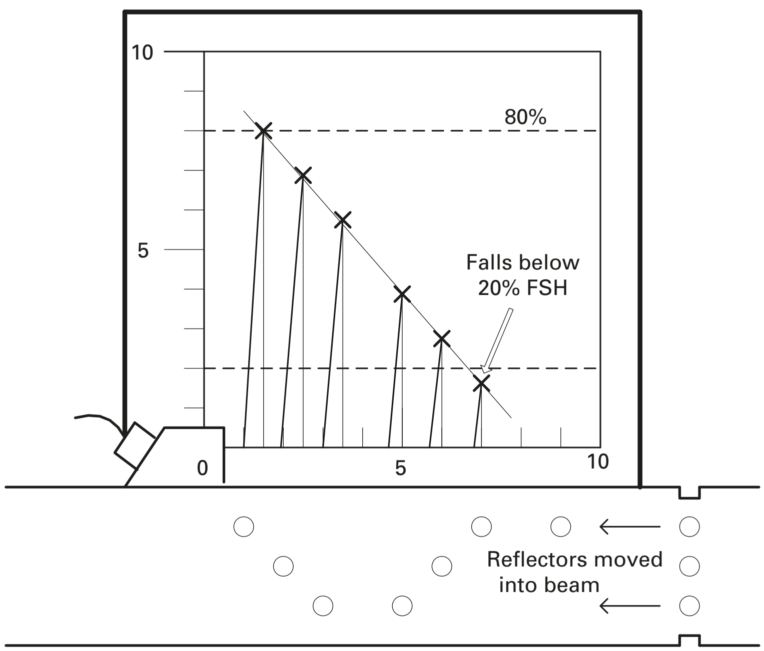


Figure Q-421
First DAC Curve

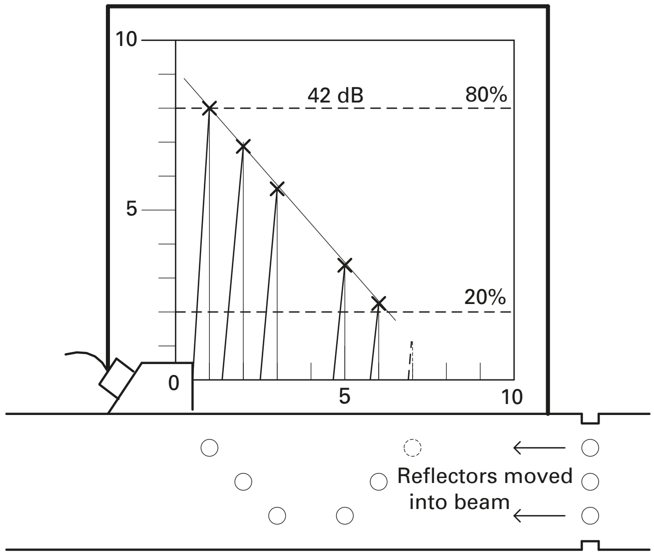
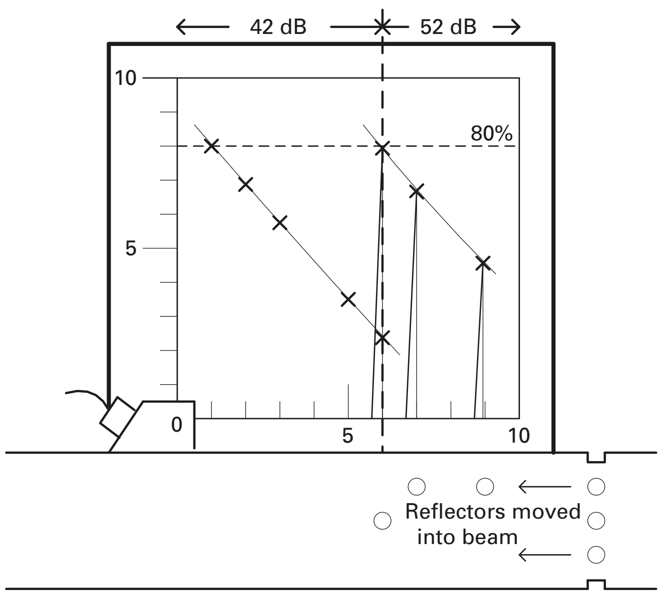


Figure Q-422
Second DAC Curve



NONMANDATORY APPENDIX R STRAIGHT BEAM CALIBRATION BLOCKS FOR RESTRICTED ACCESS WELD EXAMINATIONS

R-410 SCOPE

This Appendix is to be used as an aid for the fabrication of calibration blocks used for straight beam examinations of welds that cannot be fully examined from two directions using the angle beam technique (e.g., corner and tee joints) per T-472.2.

R-420 GENERAL

When using standard angle beam calibration blocks for the straight beam calibration of restricted access weld examinations (Figure T-434.2.1), these blocks typically do not provide an adequate distance range that encompasses the volume to be examined. When this occurs a second calibration block shall be fabricated from thicker material, with the same sized reference reflectors per T-434.2.1, spaced over the distance range that ensures examination volume coverage.

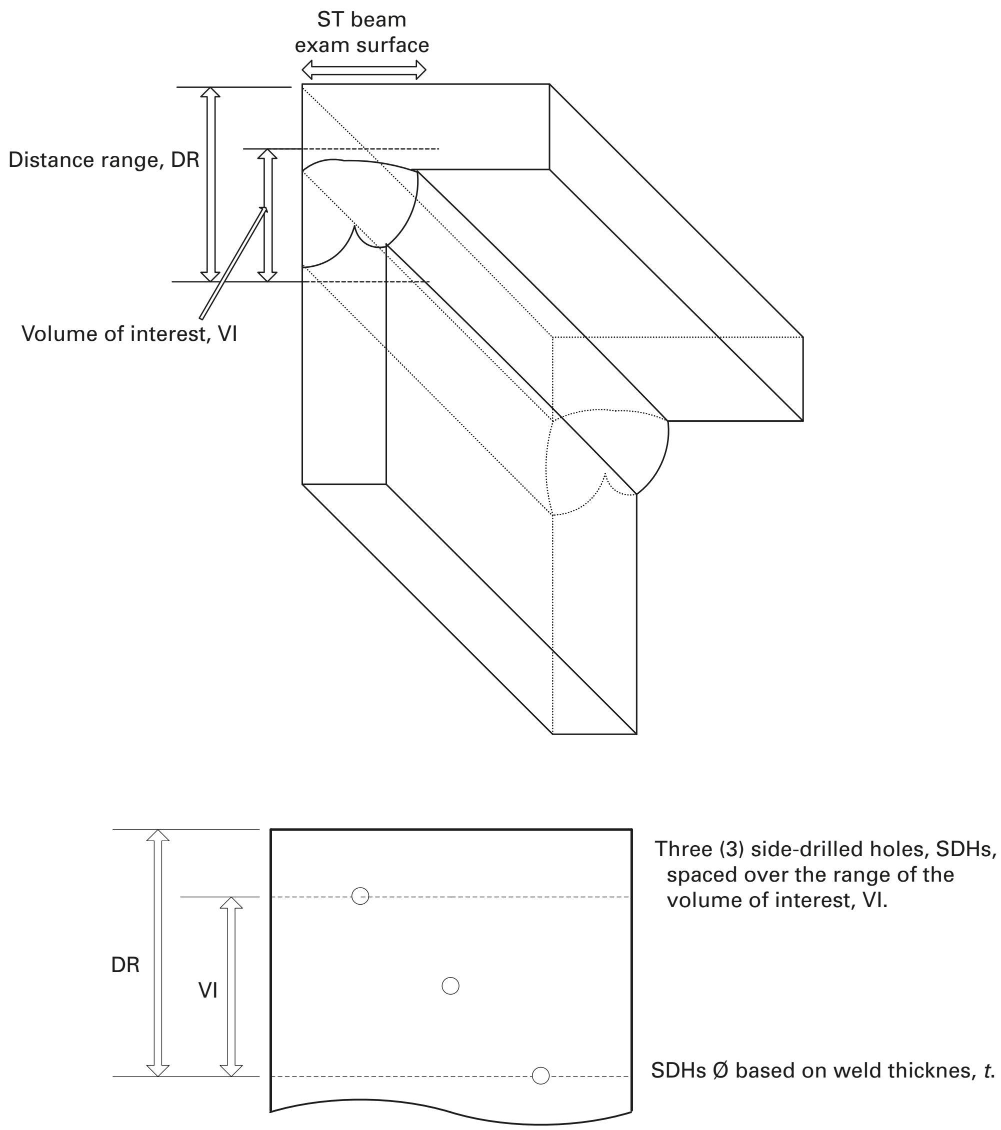
R-430 EQUIPMENT

R-434 CALIBRATION BLOCKS

(a) Corner Weld Example. Figure R-434-1 is an example of the calibration block configuration for a straight beam examination of a corner weld.

(b) Tee Weld Example. Figure R-434-2 is an example of the calibration block configuration for a straight beam examination of a tee weld.

Figure R-434-1
Corner Weld Example

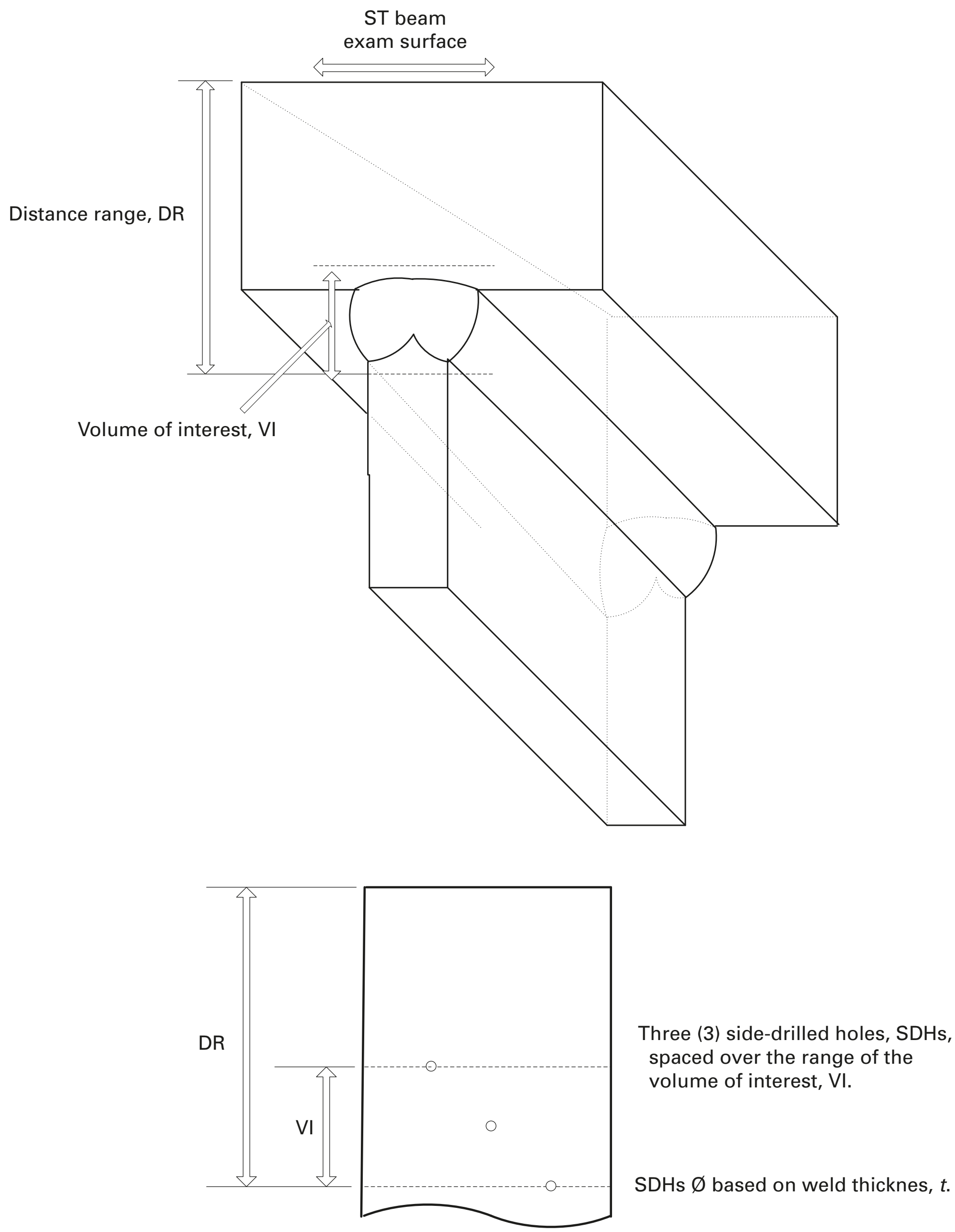


GENERAL NOTES:

(a) The top illustration shows the weld details for the determination of the volume of interest (VI). The calibration block does not require a weld unless required by the referencing Code Section or T-451.

(b) Block details and tolerances are the same as that required for standard calibration blocks per T-434.2.

Figure R-434-2
Tee Weld Example



GENERAL NOTES:

(a) The top illustration shows the weld details for the determination of the volume of interest (VI). The calibration block does not require a weld unless required by the referencing Code Section or T-451.

(b) Block details and tolerances are the same as that required for standard calibration blocks per T-434.2.

ARTICLE 5
ULTRASONIC EXAMINATION METHODS FOR MATERIALS

T-510 SCOPE

This Article provides or references requirements, which are to be used in selecting and developing ultrasonic examination procedures for parts, components, materials, and all thickness determinations. When SA, SB, and SE documents are referenced, they are located in Article 23. The referencing Code Section shall be consulted for specific requirements for the following:

(a) personnel qualification/certification requirements;

(b) procedure requirements/demonstration, qualification, acceptance;

(c) examination system characteristics;

(d) retention and control of calibration blocks;

(e) extent of examination and/or volume to be scanned;

(f) acceptance standards;

(g) retention of records, and

(h) report requirements.

Definitions of terms used in this Article are contained in Article 1, Mandatory Appendix I, I-121.2, UT — Ultrasonics.

T-520 GENERAL

T-521 BASIC REQUIREMENTS

The requirements of this article shall be used together with Article 1, General Requirements.

T-522 WRITTEN PROCEDURE REQUIREMENTS

T-522.1 Requirements. Ultrasonic examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-522. The written procedure shall establish a single value, or range of values, for each requirement.

T-522.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-522 identified as an *essential variable* from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential variable* from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

T-530 EQUIPMENT

T-531 INSTRUMENT

A pulse-echo type of ultrasonic instrument shall be used. The instrument shall be capable of operation at frequencies over the range of at least 1 to 5 MHz, and shall be equipped with a stepped gain control in units of 2.0 dB or less. If the instrument has a damping control, it may be used if it does not reduce the sensitivity of the examination. The reject control shall be in the "off" position for all examinations unless it can be demonstrated that it does not affect the linearity of the examination.

T-532 SEARCH UNITS

The nominal frequency shall be from 1 MHz to 5 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution. Search units with contoured contact wedges may be used to aid ultrasonic coupling.

T-533 COUPLANT

T-533.1 General. The couplant, including additives, shall not be detrimental to the material being examined.

T-533.2 Control of Contaminants.

(a) Couplants used on nickel base alloys shall not contain more than 250 ppm of sulfur.

(b) Couplants used on austenitic stainless steel or titanium shall not contain more than 250 ppm of halides (chlorides plus fluorides).

T-534 CALIBRATION BLOCK REQUIREMENTS

The material from which the block is fabricated shall be

(a) the same product form,

(b) the same material specification or equivalent P-Number grouping, and

(c) of the same heat treatment as the material being examined.

For the purposes of this paragraph, *product form* is defined as wrought or cast, and P-Nos. 1, 3, 4, 5A through 5C, and 15A through 15F materials are considered equivalent.

Table T-522
Variables of an Ultrasonic Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Material types and configurations to be examined, including thickness dimensions and product form (castings, forgings, plate, etc.)	X	...
The surfaces from which the examination shall be performed	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...
Search unit type(s), frequency(ies), and element size(s)/shape(s)	X	...
Special search units, wedges, shoes, or saddles, when used	X	...
Ultrasonic instrument(s)	X	...
Calibration [calibration block(s) and technique(s)]	X	...
Directions and extent of scanning	X	...
Scanning (manual vs. automatic)	X	...
Method for sizing indications	X	...
Computer enhanced data acquisition, when used	X	...
Scan overlap (decrease only)	X	...
Personnel performance requirements, when required	X	...
Personnel qualification requirements	...	X
Surface condition (examination surface, calibration block)	...	X
Couplant: brand name or type	...	X
Post-examination cleaning technique	...	X
Automatic alarm and/or recording equipment, when applicable	...	X
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X

The finish on the scanning surface of the block shall be representative of the scanning surface finish on the material to be examined.

T-534.1 Tubular Product Calibration Blocks.

(a) The calibration reflectors shall be longitudinal (axial) notches and shall have a length not to exceed 1 in. (25 mm), a width not to exceed $^1/_{16}$ in. (1.5 mm), and depth not to exceed 0.004 in. (0.10 mm) or 5% of the nominal wall thickness, whichever is larger.

(b) The calibration block shall be long enough to simulate the handling of the product being examined through the examination equipment.

T-534.2 Casting Calibration Blocks. Calibration blocks shall be the same thickness ±25% as the casting to be examined.

T-534.3 Bolting Material Calibration Blocks and Examination Techniques.[20] Calibration blocks in accordance with Figure T-534.3 shall be used for straight beam examination.

T-560 CALIBRATION

T-561 INSTRUMENT LINEARITY CHECKS

The requirements of T-561.1 and T-561.2 shall be met at intervals not to exceed three months for analog type instruments and one year for digital type instruments, or prior to first use thereafter.

T-561.1 Screen Height Linearity. The ultrasonic instrument's (excludes instruments used for thickness measurement) screen height linearity shall be evaluated in accordance with Mandatory Appendix I of Article 4.

T-561.2 Amplitude Control Linearity. The ultrasonic instrument's (excludes instruments used for thickness measurement) amplitude control linearity shall be evaluated in accordance with Mandatory Appendix II of Article 4.

T-562 GENERAL CALIBRATION REQUIREMENTS

T-562.1 Ultrasonic System. Calibrations shall include the complete ultrasonic system and shall be performed prior to use of the system in the thickness range under examination.

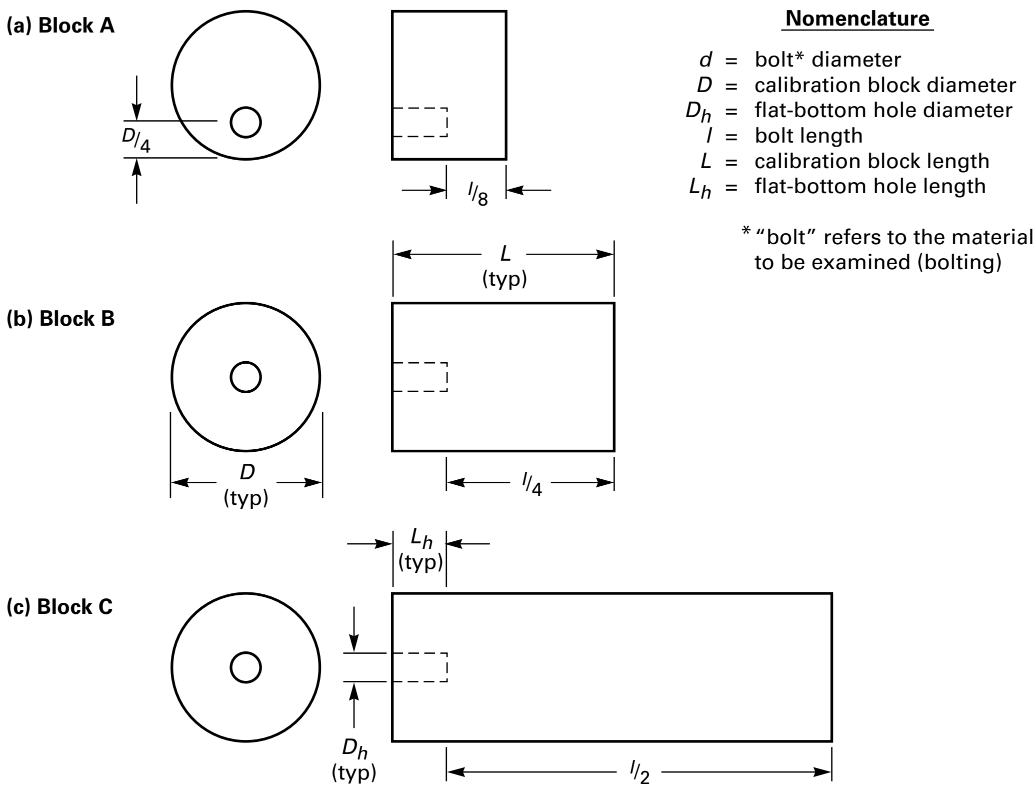
T-562.2 Calibration Surface. Calibrations shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the material from which the examination will be performed.

T-562.3 Couplant. The same couplant to be used during the examination shall be used for calibration.

T-562.4 Contact Wedges. The same contact wedges to be used during the examination shall be used for calibration.

T-562.5 Instrument Controls. Any control, which affects instrument linearity (e.g., filters, reject, or clipping), shall be in the same position for calibration, calibration checks, instrument linearity checks, and examination.

Figure T-534.3
Straight Beam Calibration Blocks for Bolting



Calibration Block Designation	Flat-Bottom Hole Depth, L_h
A	1.5 in. (38 mm)
B	0.5 in. (13 mm)
C	0.5 in. (13 mm)

Diameter of Bolting Material to be Examined, *d*	Calibration Block Diameter, *D*	Flat-Bottom Hole Diameter, D_h
Up to 1 in. (25 mm)	$d \pm d/4$	$1/16$ in. (1.5 mm)
Over 1 in. (25 mm) to 2 in. (50 mm)	$d \pm d/4$	$1/8$ in. (3 mm)
Over 2 in. (50 mm) to 3 in. (75 mm)	$d \pm d/4$	$3/16$ in. (5 mm)
Over 3 in. (75 mm) to 4 in. (100 mm)	$d \pm d/4$	$5/16$ in. (8 mm)
Over 4 in. (100 mm)	$d \pm$ 1 in. (25 mm)	$3/8$ in. (10 mm)

GENERAL NOTE: A tolerance of ±5% may be applied.

T-562.6 Temperature. For contact examination, the temperature differential between the calibration block and examination surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature for examination.

T-563 CALIBRATION CONFIRMATION

T-563.1 System Changes. When any part of the examination system is changed, a calibration check shall be made on the calibration block to verify that distance range points and sensitivity setting(s) satisfy the requirements of T-563.3.

T-563.2 Calibration Checks. A calibration check on at least one of the reflectors in the calibration block or a check using a simulator shall be performed at the completion of each examination or series of similar examinations, and when examination personnel (except for automated equipment) are changed. The distance range and sensitivity values recorded shall satisfy the requirements of T-563.3.

NOTE: Interim calibration checks between the required initial calibration and the final calibration check may be performed. The decision to perform interim calibration checks should be based on ultrasonic instrument stability (analog vs. digital), the risk of having to conduct reexaminations, and the benefit of not performing interim calibration checks.

T-563.2.1 Simulator Checks. Any simulator checks that are used shall be correlated with the original calibration on the calibration block during the original calibration. The simulator checks may use different types of calibration reflectors or blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the calibration block, every three months or prior to first use thereafter.

T-563.3 Confirmation Acceptance Values.

T-563.3.1 Distance Range Points. If any distance range point has moved on the sweep line by more than 10% of the distance reading or 5% of full sweep (whichever is greater), correct the distance range calibration and note the correction in the examination record. All recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-563.3.2 Sensitivity Settings. If any sensitivity setting has changed by more than 20% or 2 dB of its amplitude, correct the sensitivity calibration and note the correction in the examination record. If the sensitivity setting has decreased, all data sheets since the last valid calibration or calibration check shall be marked void and the area covered by the voided data shall be reexamined. If the sensitivity setting has increased, all recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-564 CASTING CALIBRATION FOR SUPPLEMENTARY ANGLE BEAM EXAMINATIONS

For supplementary angle-beam examinations, the instrument gain shall be adjusted during calibration such that the indication from the side-drilled hole producing the highest amplitude is 80% ± 5% of full screen height. This shall be the primary reference level.

T-570 EXAMINATION

T-571 EXAMINATION OF PRODUCT FORMS

T-571.1 Plate. Plate shall be examined in accordance with SA-435/SA-435M, SA-577/SA-577M, SA-578/SA-578M, or SB-548, as applicable, except as amended by the requirements elsewhere in this Article.

T-571.2 Forgings and Bars.

(a) Forgings and bars shall be examined in accordance with SA-388/SA-388M or SA-745/SA-745M, as applicable, except as amended by the requirements elsewhere in this Article.

(b) All forgings and bars shall be examined by the straight-beam examination technique.

(c) In addition to (b), ring forgings and other hollow forgings shall also be examined by the angle-beam examination technique in two circumferential directions, unless wall thickness or geometric configuration makes angle-beam examination impractical.

(d) In addition to (b) and (c), ring forgings made to fine grain melting practices and used for vessel shell sections shall be also examined by the angle-beam examination technique in two axial directions.

(e) Immersion techniques may be used.

T-571.3 Tubular Products. Tubular products shall be examined in accordance with SE-213 or SE-273, as applicable, except as amended by the requirements elsewhere in this Article.

T-571.4 Castings. Castings shall be examined in accordance with SA-609/SA-609M, except as amended by the requirements elsewhere in this Article.

(a) For straight-beam examinations, the sensitivity compensation in paragraph 8.3 of SA-609/SA-609M shall not be used.

(b) A supplementary angle-beam examination shall be performed on castings or areas of castings where a back reflection cannot be maintained during straight-beam examination, or where the angle between the front and back surfaces of the casting exceeds 15 deg.

T-571.5 Bolting Material. Bolting material shall be examined in accordance with SA-388/SA-388M, except as amended by the requirements elsewhere in this Article.

(a) Bolting material shall be examined radially prior to threading. Sensitivity shall be established using the indication from the side of the hole in calibration block A at radial metal paths of $D/4$ and $3D/4$. The instrument gain shall be adjusted such that the indication from the $D/4$ or $3D/4$ hole (whichever has the highest indication amplitude) is 80% ± 5% of full screen height (FSH). This shall be the primary reference level. A distance–amplitude correction (DAC) curve shall be established using the indications from the $D/4$ and $3D/4$ holes and shall be extended to cover the full diameter of the material being examined.

(b) Bolting material shall be examined axially from both end surfaces, either before or after threading. The instrument gain shall be adjusted such that the indication from the flat-bottom hole producing the highest indication amplitude, is 80% ± 5% FSH. This shall be the primary reference level. A DAC curve shall be established using the indications from the three flat-bottom holes and shall be extended to cover the full length of the material being examined. If any flat-bottom hole indication amplitude is less than 20% FSH, construct two DAC lines using calibration blocks A and B, and calibration blocks B and C and record the gain setting necessary to adjust the highest indication amplitude for each DAC to 80% ± 5% FSH.

(c) Immersion techniques may be used.

T-572 EXAMINATION OF PUMPS AND VALVES

Ultrasonic examination of pumps and valves shall be in accordance with Mandatory Appendix I.

T-573 INSERVICE EXAMINATION

T-573.1 Nozzle Inner Radius and Inner Corner Region. Inservice examination of nozzle inner radii and inner corner regions shall be in accordance with Mandatory Appendix II.

T-573.2 Inservice Examination of Bolting. Inservice examination of bolting shall be in accordance with Mandatory Appendix IV.

T-573.3 Inservice Examination of Cladding. Inservice examination of cladding, excluding weld metal overlay cladding, shall be in accordance with SA-578/SA-578M.

T-574 THICKNESS MEASUREMENT

Thickness measurement shall be performed in accordance with SE-797, except as amended by the requirements elsewhere in this Article.

T-577 POST-EXAMINATION CLEANING

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical after evaluation and documentation using a process that does not adversely affect the part.

T-580 EVALUATION

For examinations using DAC calibrations, any imperfection with an indication amplitude in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-590 DOCUMENTATION

T-591 RECORDING INDICATIONS

T-591.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-591.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indication (i.e., crack, lamination, inclusion, etc.), location, and extent (i.e., length) shall be recorded.

T-592 EXAMINATION RECORDS

For each ultrasonic examination, the requirements of Article 1, T-190(a) and the following information shall be recorded:

(a) ultrasonic instrument identification (including manufacturer's serial number)

(b) search unit(s) identification (including manufacturer's serial number, frequency, and size)

(c) beam angle(s) used

(d) couplant used, brand name or type

(e) search unit cable(s) used, type and length

(f) special equipment, when used (search units, wedges, shoes, automatic scanning equipment, recording equipment, etc.)

(g) computerized program identification and revision, when used

(h) calibration block identification

(i) simulation block(s) and electronic simulator(s) identification, when used

(j) instrument reference level gain and, if used, damping and reject setting(s)

(k) calibration data [including reference reflector(s), indication amplitude(s), and distance reading(s)]

(l) data correlating simulation block(s) and electronic simulator(s), when used, with initial calibration

(m) identification of material or volume scanned

(n) surface(s) from which examination was conducted, including surface condition

(o) map or record of rejectable indications detected or areas cleared

(p) areas of restricted access or inaccessible areas

Items (a) through (l) may be included or attached in a separate calibration record provided the calibration record is included in the examination record.

T-593 REPORT

A report of the examinations shall be made. The report shall include those records indicated in T-591 and T-592. The report shall be filed and maintained in accordance with the referencing Code Section.

T-594 STORAGE MEDIA

Storage media for computerized scanning data and viewing software shall be capable of securely storing and retrieving data for the time period specified by the referencing Code Section.

MANDATORY APPENDIX I
ULTRASONIC EXAMINATION OF PUMPS AND VALVES

I-510 SCOPE

This Appendix describes supplementary requirements to Article 5 for ultrasonic examination of welds or base material repairs, or both, in pumps and valves.

I-530 EQUIPMENT

I-531 CALIBRATION BLOCKS

Calibration blocks for pumps and valves shall be in accordance with Article 4, Nonmandatory Appendix J.

I-560 CALIBRATION

I-561 SYSTEM CALIBRATION

System calibration shall be in accordance with Article 4, T-463 exclusive of T-463.1.1.

I-570 EXAMINATION

The examination shall be in accordance with Article 4, T-470.

MANDATORY APPENDIX II INSERVICE EXAMINATION OF NOZZLE INSIDE CORNER RADIUS AND INNER CORNER REGIONS

II-510 SCOPE

This Appendix describes supplementary requirements to Article 5 for inservice examination of nozzle inside corner radius and inner corner regions.

II-530 EQUIPMENT

II-531 CALIBRATION BLOCKS

Calibration blocks shall be full-scale or partial-section (mockup) nozzles, which are sufficient to contain the maximum sound beam path, examination volume, and calibration reflectors.

II-531.1 General. The general calibration block requirements of Article 4, T-434.1 shall apply.

II-531.2 Mockups. If sound beams only pass through nozzle forgings during examinations, nozzle mockups may be nozzle forgings, or segments of forgings, fixed in structures as required to simulate adjacent vessel surfaces. If sound beams pass through nozzle-to-shell welds during examinations, nozzle mockups shall contain nozzle welds and shell components of sufficient size to permit calibration.

II-531.3 Thickness. The calibration block shall equal or exceed the maximum component thickness to be examined.

II-531.4 Reflectors. The calibration block shall contain a minimum of three notches within the examination volume. Alternatively, induced or embedded cracks may be used in lieu of notches, which may also be employed for demonstration of sizing capabilities when required by the referencing Code Section. Notches or cracks shall meet the following requirements:

(a) Notches or cracks shall be distributed radially in two zones with at least one notch or crack in each zone. Zone 1 ranges between 0 deg and 180 deg (±45 deg) and Zone 2 is the remaining two quadrants, centered on the nozzle's axis.

(b) Notches or cracks shall be placed within the nozzle inner radii examination volume and oriented parallel to the axial plane of the nozzle; the orientation tolerance is ±2 deg.

(c) Notch or crack lengths shall be 1 in. (25 mm) maximum. Nominal notch widths shall be $^1/_{16}$ in. (1.5 mm).

(d) Notch or crack depths, measured from the nozzle inside surface, shall be:

(1) Reflector No. 1 — 0.20 in. to 0.35 in. (5 mm to 9 mm)

(2) Reflector No. 2 — 0.35 in. to 0.55 in. (9 mm to 14 mm)

(3) Reflector No. 3 — 0.55 in. to 0.75 in. (14 mm to 19 mm)

II-560 CALIBRATION

II-561 SYSTEM CALIBRATION

System calibration shall be in accordance with Article 4, T-463 exclusive of T-463.1.1.

II-570 EXAMINATION

The general examination requirements of Article 4, T-471 shall apply.

MANDATORY APPENDIX IV
INSERVICE EXAMINATION OF BOLTS

IV-510 SCOPE

This Appendix describes supplementary requirements to Article 5 for inservice examination of bolts.

IV-530 EQUIPMENT

IV-531 CALIBRATION BLOCKS

Calibration blocks shall be full-scale or partial-section bolts, which are sufficient to contain the maximum sound beam path and area of interest, and to demonstrate the scanning technique.

IV-531.1 Material. The calibration block shall be of the same material specification, product form, and surface finish as the bolt(s) to be examined.

(19) **IV-531.2 Reflectors.** Calibration reflectors shall be straight-cut notches. A minimum of two notches shall be machined in the calibration standard, located at the minimum and maximum metal paths, except that notches need not be located closer than one bolt diameter from either end. Notch depths shall be as follows:

Bolt Diameter	Notch Depth [Note (1)]
Less than 2 in. (50 mm)	1 thread depth
2 in. (50 mm) and greater, but less than 3 in. (75 mm)	$^5/_{64}$ in. (2.0 mm)
3 in. (75 mm) and greater	$^3/_{32}$ in. (2.5 mm)

NOTE:
(1) Measured from bottom of thread root to bottom of notch.

As an alternative to straight-cut notches, other notches (e.g., circular cut) may be used provided the area of the notch does not exceed the area of the applicable straight-cut notches required by this paragraph.

IV-560 CALIBRATION

IV-561 DAC CALIBRATION

A DAC curve shall be established using the calibration reflectors in IV-531.2. The sound beam shall be directed toward the calibration reflector that yields the maximum response, and the instrument shall be set to obtain an 80% of full screen height indication. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the other calibration reflector(s) to generate a DAC curve. The calibration shall establish both the sweep range calibration and the distance–amplitude correction.

IV-570 EXAMINATION

IV-571 GENERAL EXAMINATION REQUIREMENTS

The general examination requirements of Article 4, T-471 shall apply.

ARTICLE 6
LIQUID PENETRANT EXAMINATION

T-610 SCOPE

When specified by the referencing Code Section, the liquid penetrant examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-165, Standard Test Method for Liquid Penetrant Examination. This document provides details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the liquid penetrant method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article appear in Article 1, Mandatory Appendix I, I-121.3, PT — Liquid Penetrants.

T-620 GENERAL

The liquid penetrant examination method is an effective means for detecting discontinuities which are open to the surface of nonporous metals and other materials. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, laminations, and porosity.

In principle, a liquid penetrant is applied to the surface to be examined and allowed to enter discontinuities. All excess penetrant is then removed, the part is dried, and a developer is applied. The developer functions both as a blotter to absorb penetrant that has been trapped in discontinuities, and as a contrasting background to enhance the visibility of penetrant indications. The dyes in penetrants are either color contrast (visible under white light) or fluorescent (visible under ultraviolet light).

T-621 WRITTEN PROCEDURE REQUIREMENTS

T-621.1 Requirements. Liquid penetrant examination shall be performed in accordance with a written procedure which shall as a minimum, contain the requirements listed in Table T-621.1. The written procedure shall establish a single value, or range of values, for each requirement.

T-621.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-621.1 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-621.3 Minimum and Maximum Step Times. The written procedure shall have minimum and maximum times for the applicable examination steps listed in Table T-621.3.

T-630 EQUIPMENT

The term *penetrant materials*, as used in this Article, is intended to include all penetrants, emulsifiers, solvents or cleaning agents, developers, etc., used in the examination process. The descriptions of the liquid penetrant classifications and material types are provided in SE-165 of Article 24.

T-640 MISCELLANEOUS REQUIREMENTS

T-641 CONTROL OF CONTAMINANTS

The user of this Article shall obtain certification of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic or duplex stainless steels, and titanium. These certifications shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with Mandatory Appendix II of this Article. These records shall be maintained as required by the referencing Code Section.

T-642 SURFACE PREPARATION

(a) In general, satisfactory results may be obtained when the surface of the part is in the as-welded, as-rolled, as-cast, or as-forged condition. Surface preparation by grinding, machining, or other methods may be necessary where surface irregularities could mask indications.

(b) Prior to each liquid penetrant examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux, weld spatter, paint, oil, and other extraneous matter that could obscure surface openings or otherwise interfere with the examination.

(c) Typical cleaning agents which may be used are detergents, organic solvents, descaling solutions, and paint removers. Degreasing and ultrasonic cleaning methods may also be used.

Table T-621.1
Requirements of a Liquid Penetrant Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Identification of and any change in type or family group of penetrant materials including developers, emulsifiers, etc.	X	...
Surface preparation (finishing and cleaning, including type of cleaning solvent)	X	...
Method of applying penetrant	X	...
Method of removing excess surface penetrant	X	...
Hydrophilic or lipophilic emulsifier concentration and dwell time in dip tanks and agitation time for hydrophilic emulsifiers	X	...
Hydrophilic emulsifier concentration in spray applications	X	...
Method of applying developer	X	...
Minimum and maximum time periods between steps and drying aids	X	...
Decrease in penetrant dwell time	X	...
Increase in developer dwell time (Interpretation Time)	X	...
Minimum light intensity	X	...
Surface temperature outside 40°F to 125°F (5°C to 52°C) or as previously qualified	X	...
Performance demonstration, when required	X	...
Personnel qualification requirements	...	X
Materials, shapes, or sizes to be examined and the extent of examination	...	X
Post-examination cleaning technique	...	X

(d) Cleaning solvents shall meet the requirements of T-641. The cleaning method employed is an important part of the examination process.

NOTE: Conditioning of surfaces prior to examination as required in (a) may affect the results. See SE-165, Annex A1.

T-643 DRYING AFTER PREPARATION

After cleaning, drying of the surfaces to be examined shall be accomplished by normal evaporation or with forced hot or cold air. A minimum period of time shall be established to ensure that the cleaning solution has evaporated prior to application of the penetrant.

T-650 TECHNIQUE

T-651 TECHNIQUES

Either a color contrast (visible) penetrant or a fluorescent penetrant shall be used with one of the following three penetrant processes:

(a) water washable

(b) post-emulsifying

(c) solvent removable

The visible and fluorescent penetrants used in combination with these three penetrant processes result in six liquid penetrant techniques.

Table T-621.3
Minimum and Maximum Time Limits for Steps in Penetrant Examination Procedures

Procedure Step	Minimum	Maximum
Drying after preparation (T-643)	X	...
Penetrant dwell (T-672)	X	X
Penetrant removal water washable/solvent removable (T-673.1/T-673.3)	...	...
Penetrant removal with lipophilic emulsifier [T-673.2(a)]	X	X
Penetrant removal with hydrophilic emulsifier [T-673.2(b)]		
Prerinse	...	X
Immersion	...	X
Water-emulsifier spray	...	X
Water immersion or spray post-rinse	...	X
Drying after penetrant removal (T-674)		
Solvent removal penetrants	...	X
Water-washable and post-emulsifiable penetrants	...	X
Developer application (T-675)	...	X
Developing and interpretation time (T-675.3 and T-676)	X	X

T-652 TECHNIQUES FOR STANDARD TEMPERATURES

As a standard technique, the temperature of the penetrant and the surface of the part to be processed shall not be below 40°F (5°C) nor above 125°F (52°C) throughout the examination period. Local heating or cooling is permitted provided the part temperature remains in the range of 40°F to 125°F (5°C to 52°C) during the examination. Where it is not practical to comply with these temperature limitations, other temperatures and times may be used, provided the procedures are qualified as specified in T-653.

T-653 TECHNIQUES FOR NONSTANDARD TEMPERATURES

When it is not practical to conduct a liquid penetrant examination within the temperature range of 40°F to 125°F (5°C to 52°C), the examination procedure at the proposed lower or higher temperature range requires qualification of the penetrant materials and processing in accordance with Mandatory Appendix III of this Article.

T-654 TECHNIQUE RESTRICTIONS

Fluorescent penetrant examination shall not follow a color contrast penetrant examination. Intermixing of penetrant materials from different families or different manufacturers is not permitted. A retest with water-washable penetrants may cause loss of marginal indications due to contamination.

T-660 CALIBRATION

Light meters, both visible and fluorescent (black) light meters, shall be calibrated at least once a year or whenever the meter has been repaired. If meters have not been in use for one year or more, calibration shall be done before being used.

T-670 EXAMINATION

T-671 PENETRANT APPLICATION

The penetrant may be applied by any suitable means, such as dipping, brushing, or spraying. If the penetrant is applied by spraying using compressed-air-type apparatus, filters shall be placed on the upstream side near the air inlet to preclude contamination of the penetrant by oil, water, dirt, or sediment that may have collected in the lines.

T-672 PENETRATION (DWELL) TIME

Penetration (dwell) time is critical. The minimum penetration time shall be as required in Table T-672 or as qualified by demonstration for specific applications. The maximum dwell time shall not exceed 2 hr or as qualified by demonstration for specific applications. Regardless of the length of the dwell time, the penetrant shall not be allowed to dry. If for any reason the penetrant does dry, the examination procedure shall be repeated, beginning with a cleaning of the examination surface.

T-673 EXCESS PENETRANT REMOVAL

After the specified penetration (dwell) time has elapsed, any penetrant remaining on the surface shall be removed, taking care to minimize removal of penetrant from discontinuities.

T-673.1 Water-Washable Penetrants.

(a) Excess water-washable penetrants shall be removed with a water spray. The water pressure shall not exceed 50 psi (350 kPa), and the water temperature shall not exceed 110°F (43°C).

(b) As an alternative to (a), water-washable penetrants may be removed by wiping with a clean, dry, lint-free cloth or absorbent paper, repeating the operation until most traces of penetrant have been removed. The remaining traces shall be removed by wiping the surface with a cloth or absorbent paper, lightly moistened with water. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess water.

T-673.2 Post-Emulsification Penetrants.

(a) Lipophilic Emulsification. After the required penetrant dwell time, the excess surface penetrant shall be emulsified by immersing or flooding the part with the emulsifier. Emulsification time is dependent on the type of emulsifier and surface condition. The actual emulsification time shall be determined experimentally. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

(b) Hydrophilic Emulsification. After the required penetrant dwell time, the parts may be prerinsed with water spray or directly immersed or sprayed with an emulsifier–water mixture. A prerinse allows removal of excess surface penetrant from examination objects prior to the application of hydrophilic emulsifiers. Hydrophilic emulsifiers work by detergent action. For immersion applications, examination objects must be mechanically moved in the emulsifier bath or the emulsifier must be agitated by air bubbles, so that with either method, the emulsifier comes in contact with the penetrant coating. With immersion, the concentration of the emulsifier–water bath shall be as recommended by the manufacturer. For spray applications, all part surfaces shall be uniformly sprayed with an emulsifier–water mixture. With spray applications, the emulsifier concentration shall be in accordance with the manufacturer's recommendations, but shall be no greater than 5%. The final step after emulsification is a water immersion or a water spray post-rinse to remove the emulsified penetrant. All dwell times should be kept to a minimum and shall be not more than 2 min unless a longer time is qualified on a specific part. The pressures (water emulsifier and water

Table T-672
Minimum Dwell Times

Material	Form	Type of Discontinuity	Dwell Times [Note (1)], (minutes) Penetrant
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	Castings and welds	Cold shuts, porosity, lack of fusion, cracks (all forms)	5
	Wrought materials — extrusions, forgings, plate	Laps, cracks	10
Carbide-tipped tools	Brazed or welded	Lack of fusion, porosity, cracks	5
Plastic	All forms	Cracks	5
Glass	All forms	Cracks	5
Ceramic	All forms	Cracks	5

NOTE:
(1) For temperature range from 50°F to 125°F (10°C to 52°C). For temperatures from 40°F (5°C) up to 50°F (10°C), minimum penetrant dwell time shall be 2 times the value listed.

spray) and temperatures (water and emulsifier) shall be in accordance with the requirements for water-washable penetrants.

NOTE: Additional information may be obtained from SE-165.

T-673.3 Solvent Removable Penetrants. Excess solvent removable penetrants shall be removed by wiping with a clean, dry, lint-free cloth or absorbent paper, repeating the operation until most traces of penetrant have been removed. The remaining traces shall be removed by wiping the surface with cloth or absorbent paper, lightly moistened with solvent. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess solvent.

WARNING: Flushing the surface with solvent, following the application of the penetrant and prior to developing, is prohibited.

T-674 DRYING AFTER EXCESS PENETRANT REMOVAL

(a) For the water-washable or post-emulsifying technique, the surfaces may be dried by blotting with clean materials or by using circulating air, provided the temperature of the surface is not raised above 125°F (52°C).

(b) For the solvent removable technique, the surfaces may be dried by normal evaporation, blotting, wiping, or forced air.

T-675 DEVELOPING

The developer shall be applied as soon as possible after penetrant removal; the time interval shall not exceed that established in the procedure. Insufficient coating thickness may not draw the penetrant out of discontinuities; conversely, excessive coating thickness may mask indications.

With color contrast penetrants, only a wet developer shall be used. With fluorescent penetrants, a wet or dry developer may be used.

T-675.1 Dry Developer Application. Dry developer shall be applied only to a dry surface by a soft brush, hand powder bulb, powder gun, or other means, provided the powder is dusted evenly over the entire surface being examined.

T-675.2 Wet Developer Application. Prior to applying suspension type wet developer to the surface, the developer must be thoroughly agitated to ensure adequate dispersion of suspended particles.

(a) Aqueous Developer Application. Aqueous developer may be applied to either a wet or dry surface. It shall be applied by dipping, brushing, spraying, or other means, provided a thin coating is obtained over the entire surface being examined. Drying time may be decreased by using warm air, provided the surface temperature of the part is not raised above 125°F (52°C). Blotting is not permitted.

(b) Nonaqueous Developer Application. Nonaqueous developers shall be applied by spraying, except where safety or restricted access preclude it. Under such conditions, developer may be applied by brushing. For water-washable or post-emulsifiable penetrants, the developer shall be applied to a dry surface. For solvent removable penetrants, the developer may be applied as soon as practical after excess penetrant removal. Drying shall be by normal evaporation.

T-675.3 Developing Time. Developing time for final interpretation begins immediately after the application of a dry developer or as soon as a wet developer coating is dry.

(19) T-676 INTERPRETATION

T-676.1 Final Interpretation. Final interpretation shall be made not less than 10 min nor more than 60 min after the requirements of T-675.3 are satisfied, unless otherwise qualified under T-653. If bleed-out does not alter the examination results, longer periods are permitted. If the surface to be examined is large enough to preclude complete examination within the prescribed or established time, the examination shall be performed in increments.

T-676.2 Characterizing Indication(s). The type of discontinuities are difficult to evaluate if the penetrant diffuses excessively into the developer. If this condition occurs, close observation of the formation of indication (s) during application of the developer may assist in characterizing and determining the extent of the indication(s).

T-676.3 Color Contrast Penetrants. With a color contrast penetrant, the developer forms a reasonably uniform white coating. Surface discontinuities are indicated by bleed-out of the penetrant which is normally a deep red color that stains the developer. Indications with a light pink color may indicate excessive cleaning. Inadequate cleaning may leave an excessive background making interpretation difficult. Illumination (natural or supplemental white light) of the examination surface is required for the evaluation of indications. The minimum light intensity shall be 100 fc (1 076 lx). The light intensity, natural or supplemental white light source, shall be measured with a white light meter prior to the evaluation of indications or a verified light source shall be used. Verification of light sources is required to be demonstrated only one time, documented, and maintained on file.

T-676.4 Fluorescent Penetrants. With fluorescent penetrants, the process is essentially the same as in T-676.3, with the exception that the examination is performed using an ultraviolet light, called *UV-A* light. The examination shall be performed as follows:

(a) It shall be performed in a darkened area with a maximum ambient white light level of 2 fc (21.5 lx) measured with a calibrated white light meter at the examination surface.

(b) Examiners shall be in a darkened area for at least 5 min prior to performing examinations to enable their eyes to adapt to dark viewing. Glasses or lenses worn by examiners shall not be photosensitive.

(c) The examination area shall be illuminated with UV-A lights that operate in the range between 320 nm and 400 nm.

(d) UV-A lights shall achieve a minimum of 1000 μW/cm^2 on the surface of the part being examined throughout the examination.

(e) Reflectors and filters should be checked and, if necessary, cleaned prior to use. Cracked or broken reflectors, filters, glasses, or lenses shall be replaced immediately.

(f) The UV-A light intensity shall be measured with a UV-A light meter prior to use, whenever the light's power source is interrupted or changed, and at the completion of the examination or series of examinations.

(g) Mercury vapor arc lamps produce UV-A wavelengths mainly at a peak wavelength of 365 nm for inducing fluorescence. Light-emitting diode (LED) UV-A sources using a single UV-A LED or an array of UV-A LEDs shall have emission characteristics comparable to those of other UV-A sources. LED UV-A sources shall meet the requirements of SE-2297 and SE-3022. LED UV-A light sources shall be certified as meeting the requirements of SE-3022 and/or ASTM E3022.

T-677 POST-EXAMINATION CLEANING

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical after Evaluation and Documentation using a process that does not adversely affect the part.

T-680 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Discontinuities at the surface will be indicated by bleed-out of penetrant; however, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(c) Broad areas of fluorescence or pigmentation which could mask indications of discontinuities are unacceptable, and such areas shall be cleaned and reexamined.

T-690 DOCUMENTATION

T-691 RECORDING OF INDICATIONS

T-691.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-691.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indications (linear or rounded), location and extent (length or diameter or aligned) shall be recorded.

T-692 EXAMINATION RECORDS

For each examination, the following information shall be recorded:

(a) the requirements of Article 1, T-190(a);

(b) liquid penetrant type (visible or fluorescent);

(c) type (number or letter designation) of each penetrant, penetrant remover, emulsifier, and developer used;

(d) map or record of indications per T-691;

(e) material and thickness, and;

(f) lighting equipment.

MANDATORY APPENDIX II
CONTROL OF CONTAMINANTS FOR LIQUID PENETRANT EXAMINATION

II-610 SCOPE

This Appendix contains requirements for the control of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic stainless steels, and titanium.

II-640 REQUIREMENTS

II-641 NICKEL BASE ALLOYS

When examining nickel base alloys, all penetrant materials shall be analyzed individually for sulfur content in accordance with SE-165, Annex 4. Alternatively, the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516. The sulfur content shall not exceed 0.1% by weight.

II-642 AUSTENITIC OR DUPLEX STAINLESS STEEL AND TITANIUM

When examining austenitic or duplex stainless steel and titanium, all penetrant materials shall be analyzed individually for chlorine and fluorine content in accordance with SE-165, Annex 4. Alternatively, the material may be decomposed and analyzed in accordance with SD-808 or SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine. The total chlorine and fluorine content shall not exceed 0.1% by weight.

II-643 WATER

(a) For water used in precleaning or as part of processes that involve water, if potable water (e.g., drinking, bottled, distilled, or deionized water) is used, it is not required to be analyzed for chlorine and sulfur.

(b) Any other type of water used that does not meet the requirements of (a) above shall be analyzed for chlorine in accordance with ASTM D1253 and for sulfur in accordance with SD-516. The chlorine content shall not exceed 0.1% by weight and the sulfur content shall not exceed 0.1% by weight.

II-690 DOCUMENTATION

Certifications obtained on penetrant materials shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with II-640. These records shall be maintained as required by the referencing Code Section.

MANDATORY APPENDIX III
QUALIFICATION TECHNIQUES FOR EXAMINATIONS AT NONSTANDARD TEMPERATURES

III-610 SCOPE

When a liquid penetrant examination cannot be conducted within the standard temperature range of 40°F to 125°F (5°C to 52°C), the temperature of the examination shall be qualified in accordance with this Appendix.

(19) III-630 MATERIALS

A liquid penetrant comparator block shall be made as follows. The liquid penetrant comparator blocks shall be made of aluminum, ASTM B209, Type 2024, $^{3}/_{8}$ in. (10 mm) thick, and should have approximate face dimensions of 2 in. × 3 in. (50 mm × 75 mm). At the center of each face, an area approximately 1 in. (25 mm) in diameter shall be marked with a 950°F (510°C) temperature-indicating crayon or paint. The marked area shall be heated with a blowtorch, a Bunsen burner, or similar device to a temperature between 950°F (510°C) and 975°F (524°C). The specimen shall then be immediately quenched in cold water, which produces a network of fine cracks on each face.

The block shall then be dried by heating to approximately 300°F (149°C). After cooling, the block shall be cut in half. One-half of the specimen shall be designated block "A" and the other block "B" for identification in subsequent processing. Figure III-630 illustrates the comparator blocks "A" and "B." As an alternate to cutting the block in half to make blocks "A" and "B," separate blocks 2 in. × 3 in. (50 mm × 75 mm) can be made using the heating and quenching technique as described above. Two comparator blocks with closely matched crack patterns may be used. The blocks shall be marked "A" and "B."

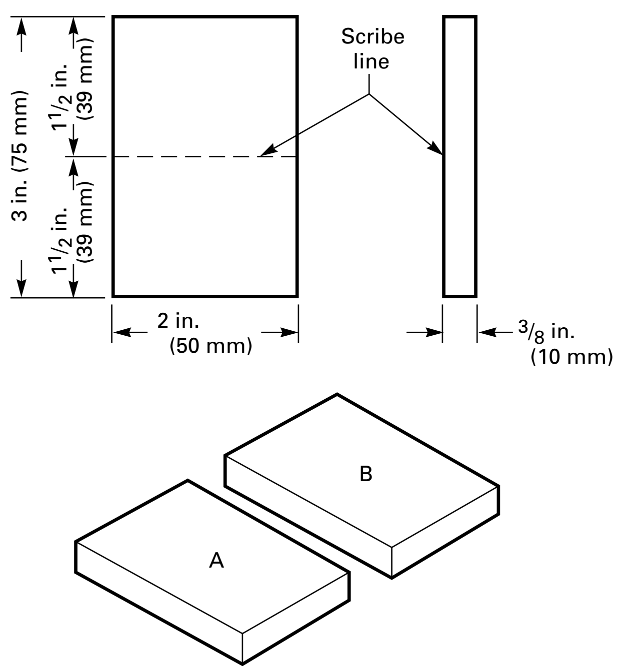
III-640 REQUIREMENTS

III-641 COMPARATOR APPLICATION

III-641.1 Temperature Less Than 40°F (5°C). If it is desired to qualify a liquid penetrant examination procedure at a temperature of less than 40°F (5°C), the proposed procedure shall be applied to block "B" after the block and all materials have been cooled and held at the proposed examination temperature until the comparison is completed. A standard procedure which has previously been demonstrated as suitable for use shall be applied to block "A" in the 40°F to 125°F (5°C to 52°C) temperature range. The indications of cracks shall be compared between blocks "A" and "B." If the indications obtained under the proposed conditions on block "B" are essentially the same as obtained on block "A" during examination at 40°F to 125°F (5°C to 52°C), the proposed procedure shall be considered qualified for use. A procedure qualified at a temperature lower than 40°F (5°C) shall be qualified from that temperature to 40°F (5°C).

III-641.2 Temperature Greater Than 125°F (52°C). If the proposed temperature for the examination is above 125°F (52°C), block "B" shall be held at this temperature throughout the examination. The indications of cracks shall be compared as described in III-641.1 while block "B" is at the proposed temperature and block "A" is at the 40°F to 125°F (5°C to 52°C) temperature range.

Figure III-630
Liquid Penetrant Comparator



GENERAL NOTE: Dimensions given are for guidance only and are not critical.

To qualify a procedure for temperatures above 125°F (52°C), for penetrants normally used in the 40°F to 125°F (5°C to 52°C) temperature range, the upper temperature limit shall be qualified and the procedure then is usable between the qualified upper temperature and the normal lower temperature of 40°F (5°C). [As an example, to qualify a penetrant normally used in the 40°F to 125°F (5°C to 52°C) temperature range at 200°F (93°C), the capability of the penetrant need only be qualified for 40°F to 200°F (5°C to 93°C) using the normal range dwell times.]

The temperature range can be any range desired by the user. For a high-temperature penetrant not normally used in the 40°F to 125°F (5°C to 52°C) temperature range, the capability of a penetrant to reveal indications on the comparator shall be demonstrated at both the lower and upper temperatures. [As an example, to qualify a high-temperature penetrant for use from 200°F to 400°F (93°C to 204°C), the capability of the penetrant to reveal indications on the comparator shall be demonstrated at 200°F to 400°F (93°C to 204°C) using the maximum observed dwell time.]

III-641.3 Alternate Techniques for Color Contrast Penetrants. As an alternate to the requirements of III-641.1 and III-641.2, when using color contrast penetrants, it is permissible to use a single comparator block for the standard and nonstandard temperatures and to make the comparison by photography.

(a) When the single comparator block and photographic technique is used, the processing details (as applicable) described in III-641.1 and III-641.2 apply. The block shall be thoroughly cleaned between the two processing steps. Photographs shall be taken after processing at the nonstandard temperature and then after processing at the standard temperature. The indication of cracks shall be compared between the two photographs. The same criteria for qualification as III-641.1 shall apply.

(b) Identical photographic techniques shall be used to make the comparison photographs.

ARTICLE 7
MAGNETIC PARTICLE EXAMINATION

(19) T-710 SCOPE

When specified by the referencing Code Section, the magnetic particle examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-709, Standard Guide for Magnetic Particle Testing. This document provides details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the magnetic particle method described in this Article shall be used together with Article 1, General Requirements. Definition of terms used in this Article are in Article 1, Mandatory Appendix I, I-121.4, MT — Magnetic Particle.

T-720 GENERAL

The magnetic particle examination method is applied to detect cracks and other discontinuities on the surfaces of ferromagnetic materials. The sensitivity is greatest for surface discontinuities and diminishes rapidly with increasing depth of discontinuities below the surface. Typical types of discontinuities that can be detected by this method are cracks, laps, seams, cold shuts, and laminations.

In principle, this method involves magnetizing an area to be examined, and applying ferromagnetic particles (the examination's medium) to the surface. Particle patterns form on the surface where the magnetic field is forced out of the part and over discontinuities to cause a leakage field that attracts the particles. Particle patterns are usually characteristic of the type of discontinuity that is detected.

Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area is to be examined at least twice, with the lines of flux during one examination being approximately perpendicular to the lines of flux during the other.

T-721 WRITTEN PROCEDURE REQUIREMENTS

T-721.1 Requirements. Magnetic particle examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-721. The written procedure shall establish a single value, or range of values, for each requirement.

T-721.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-721 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-730 EQUIPMENT

A suitable and appropriate means for producing the necessary magnetic flux in the part shall be employed, using one or more of the techniques listed in and described in T-750.

T-731 EXAMINATION MEDIUM (19)

The finely divided ferromagnetic particles used for the examination shall meet the following requirements.

(a) Particle Types. The particles shall be treated to impart color (fluorescent pigments, nonfluorescent pigments, or both) in order to make them highly visible (contrasting) against the background of the surface being examined.

(b) Particles. Dry and wet particles and suspension vehicles shall be in accordance with the applicable specifications listed in SE-709, para. 2.2.

(c) Temperature Limitations. Particles shall be used within the temperature range limitations set by the manufacturer of the particles. Alternatively, particles may be used outside the particle manufacturer's recommendations providing the procedure is qualified in accordance with Article 1, T-150 at the proposed temperature.

Table T-721
Requirements of a Magnetic Particle Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Magnetizing technique	X	...
Magnetizing current type or amperage outside range specified by this Article or as previously qualified	X	...
Surface preparation	X	...
Magnetic particles (fluorescent/visible, color, particle size, wet/dry)	X	...
Method of particle application	X	...
Method of excess particle removal	X	...
Minimum light intensity	X	...
Existing coatings, greater than the thickness demonstrated	X	...
Nonmagnetic surface contrast enhancement, when utilized	X	...
Performance demonstration, when required	X	...
Examination part surface temperature outside of the temperature range recommended by the manufacturer of the particles or as previously qualified	X	...
Shape or size of the examination object	...	X
Equipment of the same type	...	X
Temperature (within those specified by manufacturer or as previously qualified)	...	X
Demagnetizing technique	...	X
Post-examination cleaning technique	...	X
Personnel qualification requirements	...	X

T-740 MISCELLANEOUS REQUIREMENTS

T-741 SURFACE CONDITIONING

T-741.1 Preparation.

(a) Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining may be necessary where surface irregularities could mask indications due to discontinuities.

(b) Prior to magnetic particle examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil, or other extraneous matter that could interfere with the examination.

(c) Cleaning may be accomplished using detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, or ultrasonic cleaning methods.

(d) If nonmagnetic coatings are left on the part in the area being examined, it shall be demonstrated that indications can be detected through the existing maximum coating thickness applied. When AC yoke technique is used, the demonstration shall be in accordance with Mandatory Appendix I of this Article.

T-741.2 Nonmagnetic Surface Contrast Enhancement. Nonmagnetic surface contrasts may be applied by the examiner to uncoated surfaces, only in amounts sufficient to enhance particle contrast. When nonmagnetic surface contrast enhancement is used, it shall be demonstrated that indications can be detected through the enhancement. Thickness measurement of this nonmagnetic surface contrast enhancement is not required.

NOTE: Refer to T-150(a) for guidance for the demonstration required in T-741.1(d) and T-741.2.

T-750 TECHNIQUE

T-751 TECHNIQUES

One or more of the following five magnetization techniques shall be used:

(a) prod technique
(b) longitudinal magnetization technique
(c) circular magnetization technique
(d) yoke technique
(e) multidirectional magnetization technique

T-752 PROD TECHNIQUE

T-752.1 Magnetizing Procedure. For the prod technique, magnetization is accomplished by portable prod type electrical contacts pressed against the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, shall be provided to permit the current to be applied after the prods have been properly positioned.

T-752.2 Magnetizing Current. Direct or rectified magnetizing current shall be used. The current shall be 100 (minimum) amp/in. (4 amp/mm) to 125 (maximum) amp/in. (5 amp/mm) of prod spacing for sections $^{3}/_{4}$ in. (19 mm) thick or greater. For sections less than $^3/_4$ in. (19 mm) thick, the current shall be 90 amp/in. (3.6 amp/mm) to 110 amp/in. (4.4 amp/mm) of prod spacing.

T-752.3 Prod Spacing. Prod spacing shall not exceed 8 in. (200 mm). Shorter spacing may be used to accommodate the geometric limitations of the area being examined or to increase the sensitivity, but prod spacings of less than 3 in. (75 mm) are usually not practical due to banding of the particles around the prods. The prod tips shall be kept clean and dressed. If the open circuit voltage of the magnetizing current source is greater than 25 V, lead, steel, or aluminum (rather than copper) tipped prods are recommended to avoid copper deposits on the part being examined.

T-753 LONGITUDINAL MAGNETIZATION TECHNIQUE

T-753.1 Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through a multi-turn fixed coil (or cables) that is wrapped around the part or section of the part to be examined. This produces a longitudinal magnetic field parallel to the axis of the coil.

If a fixed, prewound coil is used, the part shall be placed near the side of the coil during inspection. This is of special importance when the coil opening is more than 10 times the cross-sectional area of the part.

T-753.2 Magnetic Field Strength. Direct or rectified current shall be used to magnetize parts examined by this technique. The required field strength shall be calculated based on the length L and the diameter D of the part in accordance with (a) and (b), or as established in (d) and (e), below. Long parts shall be examined in sections not to exceed 18 in. (450 mm), and 18 in. (450 mm) shall be used for the part L in calculating the required field strength. For noncylindrical parts, D shall be the maximum cross-sectional diagonal.

(a) Parts With L/D Ratios Equal to or Greater Than 4. The magnetizing current shall be within 10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{35,000}{(L/D) + 2}$$

For example, a part 10 in. (250 mm) long × 2 in. (50 mm) diameter has an L/D ratio of 5. Therefore,

$$\frac{35,000}{(L/D + 2)} = 5000\ \text{ampere-turns}$$

(b) Parts With L/D Ratios Less Than 4 but Not Less Than 2. The magnetizing ampere-turns shall be within 10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{45,000}{L/D}$$

(c) Parts With L/D Ratios Less Than 2. Coil magnetization technique cannot be used.

(d) If the area to be magnetized extends beyond 9 in. (225 mm) on either side of the coil's center, field adequacy shall be demonstrated using a magnetic field indicator or artificial flaw shims per T-764.

(e) For large parts due to size and shape, the magnetizing current shall be 1200 ampere-turns to 4500 ampere-turns. The field adequacy shall be demonstrated using artificial flaw shims or a pie-shaped magnetic field indicator in accordance with T-764. A Hall-Effect probe gaussmeter shall not be used with encircling coil magnetization techniques.

T-753.3 Magnetizing Current. The current required to obtain the necessary magnetizing field strength shall be determined by dividing the ampere-turns obtained in steps T-753.2(a) or T-753.2(b) by the number of turns in the coil as follows:

$$\text{Amperes (meter reading)} = \frac{\text{ampere-turns}}{\text{turns}}$$

For example, if a 5-turn coil is used and the ampere-turns required are 5000, use

$$\frac{5000}{5} = 1000\ \text{amperes}\ (\pm 10\%)$$

T-754 CIRCULAR MAGNETIZATION TECHNIQUE

T-754.1 Direct Contact Technique.

(a) Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through the part to be examined. This produces a *circular* magnetic field that is approximately perpendicular to the direction of current flow in the part.

(b) Magnetizing Current. Direct or rectified (half-wave rectified or full-wave rectified) magnetizing current shall be used.

(1) The current shall be 300 amp/in. (12 A/mm) to 800 amp/in. (31 A/mm) of outer diameter.

(2) For parts with geometric shapes other than round, the greatest cross-sectional diagonal in a plane at right angles to the current flow shall be used in lieu of the outer diameter in (1) above.

(3) If the current levels required for (1) cannot be obtained, the maximum current obtainable shall be used and the field adequacy shall be demonstrated in accordance with T-764.

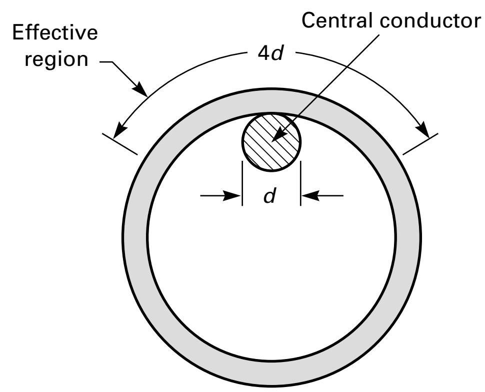
T-754.2 Central Conductor Technique.

(a) Magnetizing Procedure. For this technique, a central conductor is used to examine the internal surfaces of cylindrically or ring-shaped parts. The central conductor technique may also be used for examining the outside surfaces of these shapes. Where large diameter cylinders are to be examined, the conductor shall be positioned close to the internal surface of the cylinder. When the conductor is not centered, the circumference of the cylinder shall be examined in increments. Field strength measurements in accordance with T-764 shall be used, to determine the extent of the arc that may be examined for each conductor position or the rules in (c) below may be followed. Bars or cables, passed through the bore of a cylinder, may be used to induce circular magnetization.

(b) Magnetizing Current. The field strength required shall be equal to that determined in T-754.1(b) for a single-turn central conductor. The magnetic field will increase in proportion to the number of times the central conductor cable passes through a hollow part. For example, if 6000 A are required to examine a part using a single pass central conductor, then 3000 A are required when 2 passes of the through-cable are used, and 1200 A are required if 5 passes are used (see Figure T-754.2.1). When the central conductor technique is used, magnetic field adequacy shall be verified using a magnetic particle field indicator in accordance with T-764.

(c) Offset Central Conductor. When the conductor passing through the inside of the part is placed against an inside wall of the part, the current levels, as given in T-754.1(b)(1) shall apply, except that the diameter used for current calculations shall be the sum of the diameter of the central conductor and twice the wall thickness. The distance along the part circumference (exterior) that is effectively magnetized shall be taken as four times the diameter of the central conductor, as illustrated in Figure T-754.2.2. The entire circumference shall be inspected by rotating the part on the conductor, allowing for approximately a 10% magnetic field overlap.

Figure T-754.2.2
The Effective Region of Examination When Using an Offset Central Conductor



T-755 YOKE TECHNIQUE

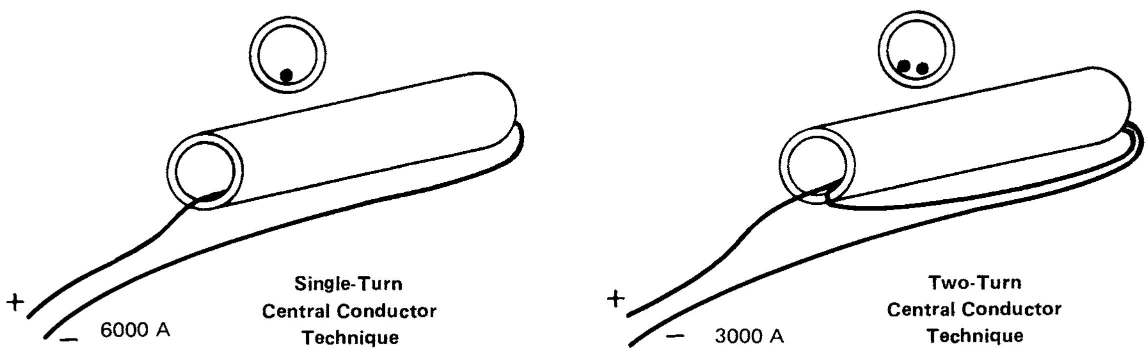
For this technique, alternating or direct current electromagnetic yokes, or permanent magnet yokes, shall be used.

T-756 MULTIDIRECTIONAL MAGNETIZATION TECHNIQUE

T-756.1 Magnetizing Procedure. For this technique, magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions. Circular or longitudinal magnetic fields may be generated in any combination using the various techniques described in T-753 and T-754.

T-756.2 Magnetic Field Strength. Only three phase, full-wave rectified current shall be used to magnetize the part. The initial magnetizing current requirements

Figure T-754.2.1
Single-Pass and Two-Pass Central Conductor Technique



for each circuit shall be established using the previously described guidelines (see T-753 and T-754). The adequacy of the magnetic field shall be demonstrated using artificial flaw shims or a pie-shaped magnetic particle field indicator in accordance with T-764. A Hall-Effect probe gaussmeter shall not be used to measure field adequacy for the multidirectional magnetization technique. An adequate field shall be obtained in at least two nearly perpendicular directions, and the field intensities shall be balanced so that a strong field in one direction does not overwhelm the field in the other direction. For areas where adequate field strengths cannot be demonstrated, additional magnetic particle techniques shall be used to obtain the required two-directional coverage.

T-760 CALIBRATION

T-761 FREQUENCY OF CALIBRATION

T-761.1 Magnetizing Equipment.

(a) Frequency. Magnetizing equipment with an ammeter shall be calibrated at least once a year, or whenever the equipment has been subjected to major electric repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

(b) Procedure. The accuracy of the unit's meter shall be verified annually by equipment traceable to a national standard. Comparative readings shall be taken for at least three different current output levels encompassing the usable range.

(c) Tolerance. The unit's meter reading shall not deviate by more than ±10% of full scale, relative to the actual current value as shown by the test meter.

T-761.2 Light Meters. Light meters shall be calibrated at least once a year or whenever a meter has been repaired. If meters have not been in use for one year or more, calibration shall be done before being used.

(19) T-762 LIFTING POWER OF YOKES

(a) The magnetizing power of yokes shall be verified prior to use each day the yoke is used. The magnetizing power of yokes shall be verified whenever the yoke has been damaged or repaired.

(b) Each alternating current electromagnetic yoke shall have a lifting power of at least 10 lb (4.5 kg) at the maximum pole spacing, with contact similar to what will be used during the examination.

(c) Each direct current or permanent magnetic yoke shall have a lifting power of at least 40 lb (18 kg) at the maximum pole spacing, with contact similar to what will be used during the examination.

(d) Each weight shall be weighed with a scale from a reputable manufacturer and stenciled with the applicable nominal weight prior to first use. A weight need only be verified again if damaged in a manner that could have caused potential loss of material.

T-763 GAUSSMETERS

Hall-Effect probe gaussmeters used to verify magnetizing field strength in accordance with T-754 shall be calibrated at least once a year or whenever the equipment has been subjected to a major repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

T-764 MAGNETIC FIELD ADEQUACY AND DIRECTION

T-764.1 Application. The use of magnetic field indicators, artificial shims, or Hall-Effect tangential-field probes are only permitted when specifically referenced by the following magnetizing techniques:

(a) Longitudinal (T-753)

(b) Circular (T-754)

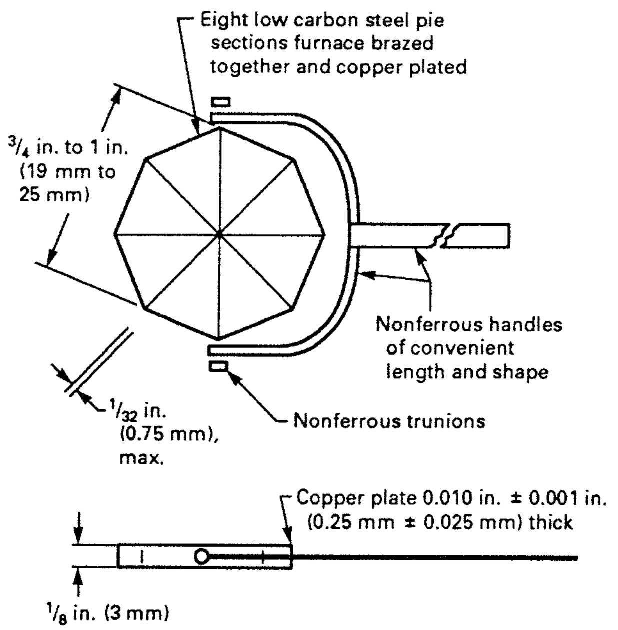
(c) Multidirectional (T-756)

T-764.2 Magnetic Field Adequacy. The applied magnetic field shall have sufficient strength to produce satisfactory indications, but shall not be so strong that it causes masking of relevant indications by nonrelevant accumulations of magnetic particles. Factors that influence the required field strength include the size, shape, and material permeability of the part; the technique of magnetization; coatings; the method of particle application; and the type and location of discontinuities to be detected. When it is necessary to verify the adequacy of magnetic field strength, it shall be verified by using one or more of the following three methods.

(a) Pie-Shaped Magnetic Particle Field Indicator. The indicator, shown in Figure T-764.2(a), shall be positioned on the surface to be examined, such that the copper-plated side is away from the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles form(s) across the copper face of the indicator when the magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed. Pie-type indicators are best used with dry particle procedures.

(b) Artificial Flaw Shims. One of the shims shown in Figure T-764.2(b)(1) or Figure T-764.2(b)(2) whose orientation is such that it can have a component perpendicular to the applied magnetic field shall be used. Shims with linear notches shall be oriented so that at least one notch is perpendicular to the applied magnetic field. Shims with only circular notches may be used in any orientation. Shims shall be attached to the surface to be examined, such that the artificial flaw side of the shim is toward the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles, representing the 30% depth flaw, appear(s) on the shim face when magnetic particles are applied simultaneously with the magnetizing force. When a

Figure T-764.2(a)
Pie-Shaped Magnetic Particle Field Indicator



clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed. Shim-type indicators are best used with wet particle procedures.

NOTE: The circular shims shown in Figure T-764.2(b)(2) illustration (b) also have flaw depths less and greater than 30%.

(c) Hall-Effect Tangential-Field Probe. A gaussmeter and Hall-Effect tangential-field probe shall be used for measuring the peak value of a tangential field. The probe shall be positioned on the surface to be examined, such that the maximum field strength is determined. A suitable field strength is indicated when the measured field is within the range of 30 G to 60 G (2.4 kAm^{-1} to 4.8 kAm^{-1}) while the magnetizing force is being applied. See Article 7, Nonmandatory Appendix A.

T-764.3 Magnetic Field Direction. The direction(s) of magnetization shall be determined by particle indications obtained using an indicator or shims as shown in Figure T-764.2(a), Figure T-764.2(b)(1), or Figure T-764.2(b)(2). When a clearly defined line of particles are not formed

(a) in the desired direction, or

(b) in at least two nearly perpendicular directions for the multidirectional technique

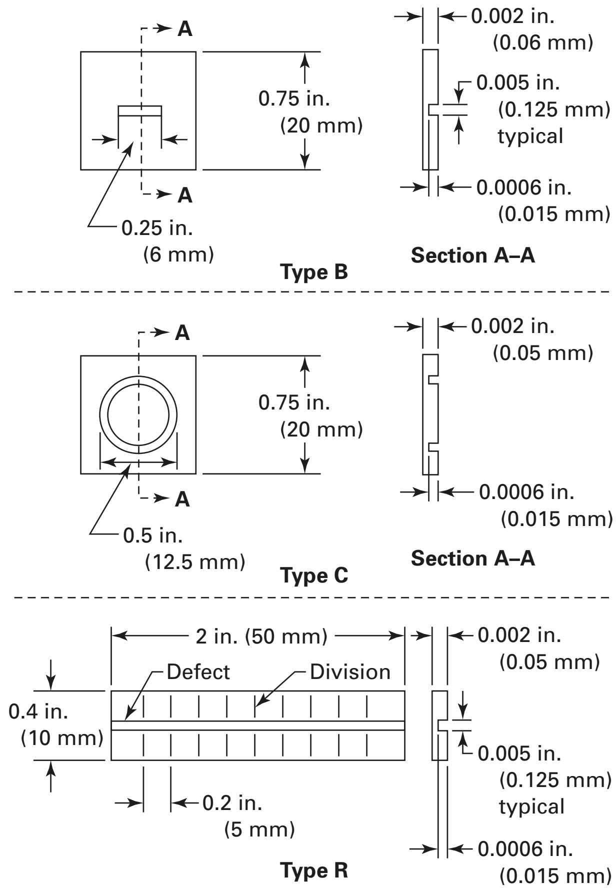
the magnetizing technique shall be changed as needed.

T-765 WET PARTICLE CONCENTRATION AND CONTAMINATION

Wet Horizontal Units shall have the bath concentration and bath contamination determined by measuring its settling volume. This is accomplished through the use of a pear-shaped centrifuge tube with a 1-mL stem (0.05-mL divisions) for fluorescent particle suspensions or a 1.5-mL stem (0.1-mL divisions) for nonfluorescent suspensions (see SE-709, Appendix X5). Before sampling, the suspension should be run through the recirculating system for at least 30 min to ensure thorough mixing of all particles which could have settled on the sump screen and along the sides or bottom of the tank.

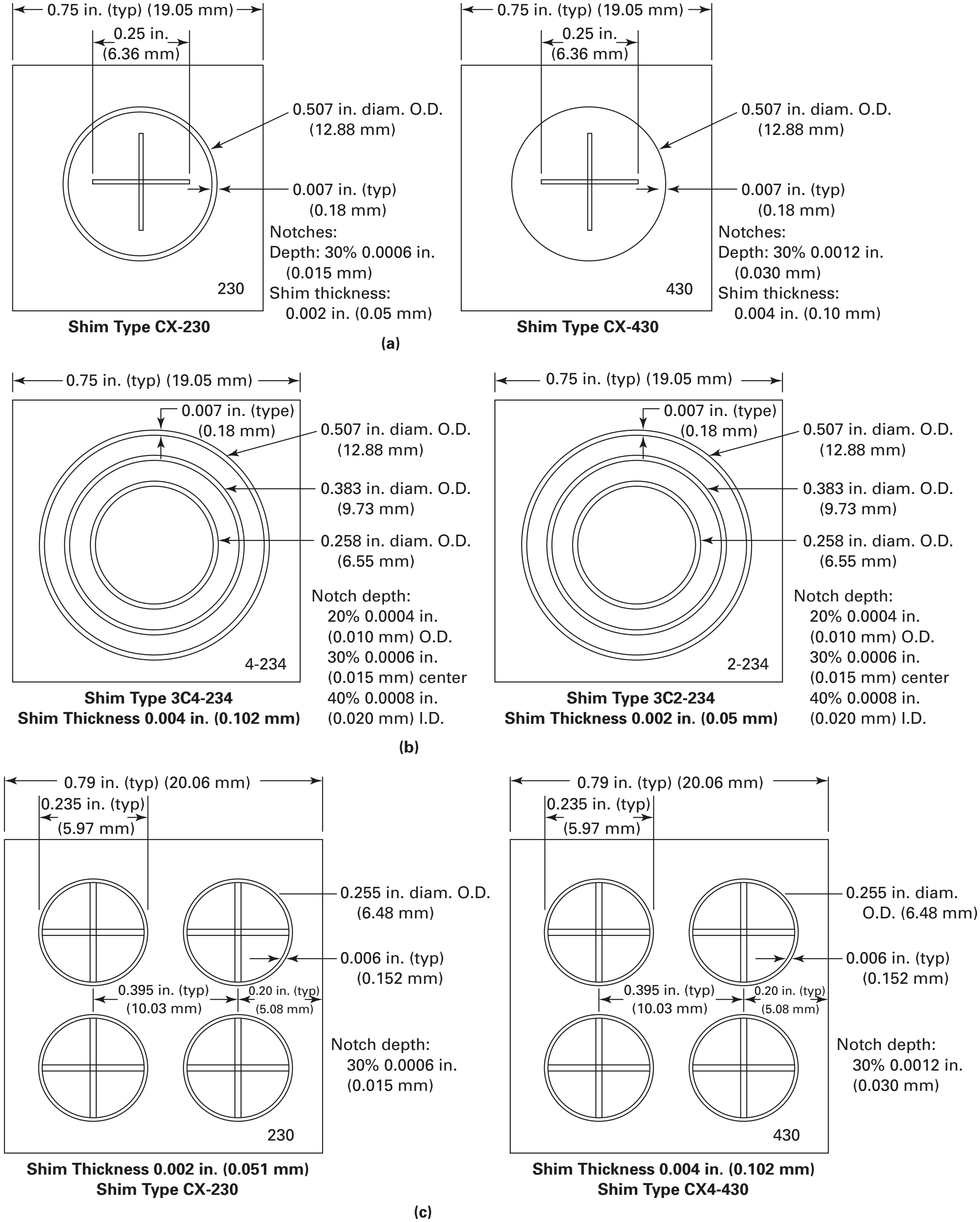
T-765.1 Concentration. Take a 100-mL portion of the suspension from the hose or nozzle, demagnetize and allow it to settle for approximately 60 min with petroleum distillate suspensions or 30 min with water-based

Figure T-764.2(b)(1)
Artificial Flaw Shims



GENERAL NOTE: Above are examples of artificial flaw shims used in magnetic particle inspection system verification (not drawn to scale). The shims are made of low carbon steel (1005 steel foil). The artificial flaw is etched or machined on one side of the foil to a depth of 30% of the foil thickness.

Figure T-764.2(b)(2)
Artificial Flaw Shims



suspensions before reading. The volume settling out at the bottom of the tube is indicative of the particle concentration in the bath.

T-765.2 Settling Volumes. For fluorescent particles, the required settling volume is from 0.1 mL to 0.4 mL in a 100-mL bath sample and from 1.2 mL to 2.4 mL per 100 mL of vehicle for nonfluorescent particles unless otherwise specified by the particle manufacturer. Concentration checks shall be made at least every eight hours.

T-765.3 Contamination. Both fluorescent and nonfluorescent suspensions shall be checked periodically for contaminants such as dirt, scale, oil, lint, loose fluorescent pigment, water (in the case of oil suspensions), and particle agglomerates which can adversely affect the performance of the magnetic particle examination process. The test for contamination shall be performed at least once per week.

(a) Carrier Contamination. For fluorescent baths, the liquid directly above the precipitate should be examined with fluorescent excitation light. The liquid will have a little fluorescence. Its color can be compared with a freshly made-up sample using the same materials or with an unused sample from the original bath that was retained for this purpose. If the "used" sample is noticeably more fluorescent than the comparison standard, the bath shall be replaced.

(b) Particle Contamination. The graduated portion of the tube shall be examined under fluorescent excitation light if the bath is fluorescent and under visible light (for both fluorescent and nonfluorescent particles) for striations or bands, differences in color or appearance. Bands or striations may indicate contamination. If the total volume of the contaminates, including bands or striations exceeds 30% of the volume magnetic particles, or if the liquid is noticeably fluorescent, the bath shall be replaced.

T-766 SYSTEM PERFORMANCE OF HORIZONTAL UNITS

The Ketos (Betz) ring specimen (see Figure T-766.1) shall be used in evaluating and comparing the overall performance and sensitivity of both dry and wet, fluorescent and nonfluorescent magnetic particle techniques using a central conductor magnetization technique.

(a) Ketos (Betz) Test Ring Material. The tool steel (Ketos) ring should be machined from AISI 01 material in accordance with Figure T-766.1. Either the machined ring or the steel blank should be annealed at 1,650°F (900°C), cooled 50°F (28°C) per hour to 1,000°F (540°C) and then air cooled to ambient temperature to give comparable results using similar rings that have had the same treatment. Material and heat treatment are important variables. Experience indicates controlling the softness of the ring by hardness (90 HRB to 95 HRB) alone is insufficient.

(b) Using the Test Ring. The test ring (see Figure T-766.1), is circularly magnetized with full-wave rectified AC passing through a central conductor with a 1 in. to $1^1/_4$ in. (25 mm to 32 mm) diameter hole located in the ring center. The conductor should have a length greater than 16 in. (400 mm). The currents used shall be 1400 A, 2500 A, and 3400 A. The minimum number of holes shown shall be three, five, and six, respectively. The ring edge should be examined with either black light or visible light, depending on the type of particles involved. This test shall be run at the three amperages if the unit will be used at these or higher amperages. The amperage values stated shall not be exceeded in the test. If the test does not reveal the required number of holes, the equipment shall be taken out of service and the cause of the loss of sensitivity determined and corrected. This test shall be run at least once per week.

T-770 EXAMINATION

T-771 PRELIMINARY EXAMINATION

Before the magnetic particle examination is conducted, a check of the examination surface shall be conducted to locate any surface discontinuity openings which may not attract and hold magnetic particles because of their width.

T-772 DIRECTION OF MAGNETIZATION

At least two separate examinations shall be performed on each area. During the second examination, the lines of magnetic flux shall be approximately perpendicular to those used during the first examination. A different technique for magnetization may be used for the second examination.

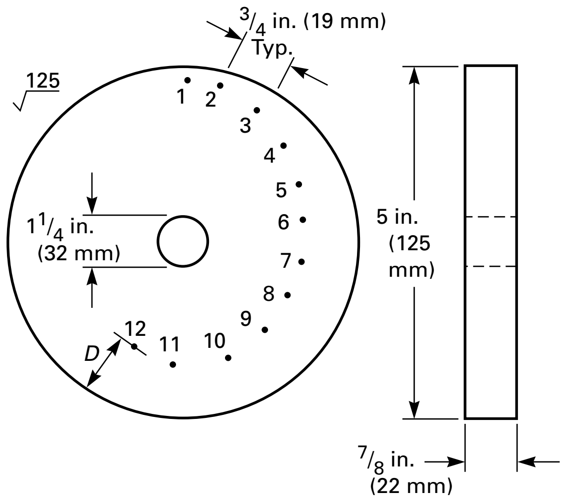
T-773 METHOD OF EXAMINATION

The ferromagnetic particles used in an examination medium can be either wet or dry, and may be either fluorescent or nonfluorescent. Examination(s) shall be done by the continuous method.

(a) Dry Particles. The magnetizing current shall remain on while the examination medium is being applied and while any excess of the examination medium is removed.

(b) Wet Particles. The magnetizing current shall be turned on after the particles have been applied. Flow of particles shall stop with the application of current. Wet particles applied from aerosol spray cans or pump sprayers may be applied before and/or during magnetizing current application. Wet particles may be applied during the application of magnetizing current if they are not applied directly to the examination area and are allowed to flow over the examination area or are applied directly to the examination area with low velocities insufficient to remove accumulated particles.

Figure T-766.1
Ketos (Betz) Test Ring



Hole	1	2	3	4	5	6	7	8	9	10	11	12
Diameter [Note (1)]	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)	0.07 (1.8)
“D” [Note (2)]	0.07 (1.8)	0.14 (3.6)	0.21 (5.3)	0.28 (7.1)	0.35 (9.0)	0.42 (10.8)	0.49 (12.6)	0.56 (14.4)	0.63 (16.2)	0.70 (18.0)	0.77 (19.8)	0.84 (21.6)

GENERAL NOTES:

(a) All dimensions are ±0.03 in. (±0.8 mm) or as noted in Notes (1) and (2).

(b) In the in-text table, all dimensions are in inches, except for the parenthesized values, which are in millimeters.

(c) Material is ANSI 01 tool steel from annealed round stock.

(d) The ring may be heat treated as follows: Heat to 1,400°F to 1,500°F (760°C to 790°C). Hold at this temperature for 1 hr. Cool to a minimum rate of 40°F/hr (22°C/h) to below 1,000°F (540°C). Furnace or air cool to room temperature. Finish the ring to RMS 25 and protect from corrosion.

NOTES:

(1) All hole diameters are ±0.005 in. (±0.1 mm.) Hole numbers 8 through 12 are optional.

(2) Tolerance on the *D* distance is ±0.005 in. (±0.1 mm).

T-774 EXAMINATION COVERAGE

All examinations shall be conducted with sufficient field overlap to ensure 100% coverage at the required sensitivity (T-764).

T-775 RECTIFIED CURRENT

(a) Whenever direct current is required rectified current may be used. The rectified current for magnetization shall be either three-phase (full-wave rectified) current, or single phase (half-wave rectified) current.

(b) The amperage required with three-phase, full-wave rectified current shall be verified by measuring the average current.

(c) The amperage required with single-phase (half-wave rectified) current shall be verified by measuring the average current output during the conducting half cycle only.

(d) When measuring half-wave rectified current with a direct current test meter, readings shall be multiplied by two.

T-776 EXCESS PARTICLE REMOVAL

Accumulations of excess dry particles in examinations shall be removed with a light air stream from a bulb or syringe or other source of low pressure dry air. The examination current or power shall be maintained while removing the excess particles.

(19) T-777 INTERPRETATION

The interpretation shall identify if an indication as false, nonrelevant, or relevant. False and nonrelevant indications shall be proven as false or nonrelevant. Interpretation shall be carried out to identify the locations of indications and the character of the indication.

T-777.1 Visible (Color Contrast) Magnetic Particles. Surface discontinuities are indicated by accumulations of magnetic particles which should contrast with the examination surface. The color of the magnetic particles shall be different than the color of the examination surface. Illumination (natural or supplemental white light) of the examination surface is required for the evaluation of indications. The minimum light intensity shall be 100 fc (1 076 lx). The light intensity, natural or supplemental white light source, shall be measured with a white light meter prior to the evaluation of indications or a verified light source shall be used. Verification of light sources is required to be demonstrated only one time, documented, and maintained on file.

T-777.2 Fluorescent Magnetic Particles. With fluorescent magnetic particles, the process is essentially the same as in T-777.1, with the exception that the examination is performed using an ultraviolet light, called *UV-A* light. The examination shall be performed as follows:

(a) It shall be performed in a darkened area with a maximum ambient white light level of 2 fc (21.5 lx) measured with a calibrated white light meter at the examination surface.

(b) Examiners shall be in a darkened area for at least 5 min prior to performing examinations to enable their eyes to adapt to dark viewing. Glasses or lenses worn by examiners shall not be photosensitive.

(c) The examination area shall be illuminated with UV-A lights that operate in the range between 320 nm and 400 nm.

(d) UV-A lights shall achieve a minimum of 1000 $\mu W/cm^2$ on the surface of the part being examined throughout the examination.

(e) Reflectors, filters, glasses, and lenses should be checked and, if necessary, cleaned prior to use. Cracked or broken reflectors, filters, glasses, or lenses shall be replaced immediately.

(f) The UV-A light intensity shall be measured with a UV-A light meter prior to use, whenever the light's power source is interrupted or changed, and at the completion of the examination or series of examinations.

(g) Mercury vapor arc lamps produce UV-A wavelengths mainly at a peak wavelength of 365 nm for inducing fluorescence. LED UV-A sources using a single UV-A LED or an array of UV-A LEDs shall have emission characteristics comparable to those of other UV-A sources. LED UV-A sources shall meet the requirements of SE-2297 and SE-3022. LED UV-A light sources shall be certified as meeting the requirements of SE-3022 and/or ASTM E3022.

T-777.3 Fluorescent Magnetic Particles With Other Fluorescent Excitation Wavelengths. Alternatively to the requirements in T-777.2, the examinations may be performed using alternate wavelength light sources which cause fluorescence in specific particle coatings. Any alternate light wavelength light sources and specific particle designations used shall be qualified[21] in accordance with Mandatory Appendix IV. The examination shall be performed as follows:

(a) It shall be performed in a darkened area.

(b) Examiners shall be in a darkened area for at least 5 min prior to performing examinations to enable their eyes to adapt to dark viewing. Glasses or lenses worn by examiners shall not be photochromic or exhibit any fluorescence.

(c) If the fluorescence excitation light source emits visible light intensities greater than 2 fc (21.5 lx), the examiner shall wear fluorescence-enhancing filter glasses approved by the light source manufacturer for use with that light source.

(d) The fluorescence excitation light source shall achieve at least the minimum light intensity on the surface of the part throughout the examination as qualified in the tests of Mandatory Appendix IV.

(e) Reflectors, filters, glasses, and lenses should be checked and, if necessary, cleaned prior to use. Cracked or broken reflectors, filters, glasses, or lenses shall be replaced immediately.

(f) The fluorescence excitation light intensity shall be measured with a suitable fluorescence excitation light meter prior to use, whenever the light's power source is interrupted or changed, and at the completion of the examination or series of examinations.

T-778 DEMAGNETIZATION

When residual magnetism in the part could interfere with subsequent processing or usage, the part shall be demagnetized any time after completion of the examination.

T-779 POST-EXAMINATION CLEANING

When post-examination cleaning is required, it should be conducted as soon as practical using a process that does not adversely affect the part.

T-780 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Discontinuities on or near the surface are indicated by retention of the examination medium. However, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(c) Broad areas of particle accumulation, which might mask indications from discontinuities, are prohibited, and such areas shall be cleaned and reexamined.

T-790 DOCUMENTATION

T-791 MULTIDIRECTIONAL MAGNETIZATION TECHNIQUE SKETCH

A technique sketch shall be prepared for each different geometry examined, showing the part geometry, cable arrangement and connections, magnetizing current for each circuit, and the areas of examination where adequate field strengths are obtained. Parts with repetitive geometries, but different dimensions, may be examined using a single sketch provided that the magnetic field strength is adequate when demonstrated in accordance with T-756.2.

T-792 RECORDING OF INDICATIONS

T-792.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-792.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indications (linear or rounded), location and extent (length or diameter or aligned) shall be recorded.

T-793 EXAMINATION RECORDS

For each examination, the following information shall be recorded:

(a) the requirements of Article 1, T-190(a)

(b) magnetic particle equipment and type of current

(c) magnetic particles (visible or fluorescent, wet or dry)

(d) map or record of indications per T-792

(e) material and thickness

(f) lighting equipment

MANDATORY APPENDIX I
MAGNETIC PARTICLE EXAMINATION USING THE AC YOKE TECHNIQUE ON FERROMAGNETIC MATERIALS COATED WITH NONFERROMAGNETIC COATINGS

I-710 SCOPE

This Appendix provides the Magnetic Particle examination methodology and equipment requirements applicable for performing Magnetic Particle examination on ferromagnetic materials with nonferromagnetic coatings.

I-720 GENERAL

Requirements of Article 7 apply unless modified by this Appendix.

I-721 WRITTEN PROCEDURE REQUIREMENTS

I-721.1 Requirements. Magnetic Particle examination shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Tables T-721 and I-721. The written procedure shall establish a single value, or range of values, for each requirement.

I-721.2 Procedure Qualification/Technique Validation. When procedure qualification is specified, a change of a requirement in Table T-721 or Table I-721 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure and validation of the technique. A change of a requirement identified as an nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

I-722 PERSONNEL QUALIFICATION

Personnel qualification requirements shall be in accordance with the referencing Code Section.

Table I-721
Requirements of AC Yoke Technique on Coated Ferritic Component

Requirement	Essential Variable	Nonessential Variable
Identification of surface configurations to be examined, including coating materials, maximum qualified coating thickness, and product forms (e.g., base material or welded surface)	X	…
Surface condition requirements and preparation methods	X	…
Manufacturer and model of AC yoke	X	…
Manufacturer and type of magnetic particles	X	…
Minimum and maximum pole separation	X	…
Identification of the steps in performing the examination	X	…
Minimum lighting intensity and AC yoke lifting power requirements [as measured in accordance with Technique Qualification (I-721.2)]	X	…
Methods of identifying flaw indications and discriminating between flaw indications and false or nonrelevant indications (e.g., magnetic writing or particles held by surface irregularities)	X	…
Instructions for identification and confirmation of suspected flaw indications	X	…
Applicator other than powder blower	X	…
Method of measuring coating thickness	…	X
Recording criteria	…	X
Personnel qualification requirements unique to this technique	…	X
Reference to the procedure qualification records	…	X

I-723 PROCEDURE/TECHNIQUE DEMONSTRATION

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

(19) I-730 EQUIPMENT

(a) The magnetizing equipment shall be in accordance with Article 7.

(b) When the dry powder technique is used, a compressed air powder blower shall be utilized for powder application in any position. Other applicators may be used if qualified in the same surface position as the examination object surface. Applicators qualified for the overhead position may be used in any other position. Applicators qualified for the vertical position may be used in the horizontal and flat positions.

(c) Magnetic particles shall contrast with the component background.

(d) Nonconductive materials such as plastic shim stock may be used to simulate nonconductive nonferromagnetic coatings for procedure and personnel qualification.

I-740 MISCELLANEOUS REQUIREMENTS

I-741 COATING THICKNESS MEASUREMENT

The procedure demonstration and performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an eddy current technique or magnetic technique may be used to measure the coating thickness. The magnetic technique shall be in accordance with SD-1186, Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base. When coatings are conductive and nonferromagnetic, a coating thickness technique shall be used in accordance with SD-1186. Coating measurement equipment shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (50 mm) maximum grid pattern over the area of examination and at least one-half the maximum yoke leg separation beyond the examination area. The thickness shall be the mean of three separate readings within $^1/_4$ in. (6 mm) of each intersection.

I-750 TECHNIQUE

I-751 TECHNIQUE QUALIFICATION

(a) A qualification specimen is required. The specimen shall be of similar geometry or weld profile and contain at least one linear surface indication no longer than $^1/_{16}$ in. (1.5 mm) in length. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. As an alternative to the material requirement, other materials and heat treatments may be qualified provided:

(1) The measured yoke maximum lifting force on the material to be examined is equal to or greater than the maximum lifting force on the qualification specimen material. Both values shall be determined with the same or comparable equipment and shall be documented as required in (c).

(2) All the requirements of (b) through (g) are met for the alternate material.

(b) Examine the uncoated specimen in the most unfavorable orientation expected during the performance of the production examination.

(c) Document the measured yoke maximum lifting power, illumination levels, and the results.

(d) Measure the maximum coating thickness on the item to be examined in accordance with the requirements of I-741.

(e) Coat the specimen with the same type of coating, conductive or nonconductive, to the maximum thickness measured on the production item to be examined. Alternately, nonconductive shim stock may be used to simulate nonconductive coatings.

(f) Examine the coated specimen in the most unfavorable orientation expected during the performance of the production examination. Document the measured yoke maximum lifting power, illumination level, and examination results.

(g) Compare the length of the indication resulting from the longest flaw no longer than the maximum flaw size allowed by the applicable acceptance criteria, before and after coating. The coating thickness is qualified when the length of the indication on the coated surface is at least 50% of the length of the corresponding indication prior to coating.

(h) Requalification of the procedure is required for a decrease in either the AC yoke lifting power or the illumination level, or for an increase in the coating thickness.

I-760 CALIBRATION

I-761 YOKE MAXIMUM LIFTING FORCE

The maximum lifting force of the AC yoke shall be determined at the actual leg separation to be used in the examination. This may be accomplished by holding the yoke with a 10 lb (4.5 kg) ferromagnetic weight between the legs of the yoke and adding additional weights, calibrated on a postage or other scale, until the ferromagnetic weight is released. The lifting power of the yoke shall be the combined weight of the ferromagnetic material and the added weights, before the ferromagnetic weight was released. Other methods may be used such as a load cell.

I-762 LIGHT INTENSITY MEASUREMENT

The black light or white light intensity (as appropriate) on the surface of the component shall be no less than that used in the qualification test. An appropriate calibrated black light and/or white light meter shall be used for the tests. Minimum white light or black light intensities shall meet the requirements of T-777.1 or T-777.2 as applicable.

I-762.1 White Light. The white light intensity shall be measured at the inspection surface. The white light intensity for the examination shall be no less than what was used in the qualification.

I-762.2 Black Light. The black light intensity shall be measured at the distance from the black light in the procedure qualification and at the same distance on the examination specimen. The black light intensity shall be no less than that used to qualify the procedure. In addition, the maximum white light intensity shall be measured as background light on the inspection surface. The background white light for the examination shall be no greater than what was used in the qualification.

I-770 EXAMINATION

(a) Surfaces to be examined, and all adjacent areas within at least 1 in. (25 mm), shall be free of all dirt, grease, lint, scale, welding flux and spatter, oil, and loose, blistered, flaking, or peeling coating.

(b) Examine the coated item in accordance with the qualified procedure.

I-780 EVALUATION

If an indication greater than 50% of the maximum allowable flaw size is detected, the coating in the area of the indication shall be removed and the examination repeated.

I-790 DOCUMENTATION

I-791 EXAMINATION RECORD

For each examination, the information required in the records section of T-793 and the following information shall be recorded:

(a) identification of the procedure/technique

(b) description and drawings or sketches of the qualification specimen, including coating thickness measurements and flaw dimensions

(c) equipment and materials used

(d) illumination level and yoke lifting power

(e) qualification results, including maximum coating thickness and flaws detected

MANDATORY APPENDIX III
MAGNETIC PARTICLE EXAMINATION USING THE YOKE TECHNIQUE WITH FLUORESCENT PARTICLES IN AN UNDARKENED AREA

III-710 SCOPE

This Appendix provides the Magnetic Particle examination methodology and equipment requirements applicable for performing Magnetic Particle examinations using a yoke with fluorescent particles in an undarkened area.

III-720 GENERAL

Requirements of Article 7 apply unless modified by this Appendix.

III-721 WRITTEN PROCEDURE REQUIREMENTS

III-721.1 Requirements. The requirements of Tables T-721 and III-721 apply.

III-721.2 Procedure Qualification. The requirements of Tables T-721 and III-721 apply.

III-723 PROCEDURE DEMONSTRATION

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

III-750 TECHNIQUE

III-751 QUALIFICATION STANDARD

A standard slotted shim(s) as described in T-764.2(b) shall be used as the qualification standard.

III-760 CALIBRATION

III-761 BLACK LIGHT INTENSITY MEASUREMENT

The black light intensity on the surface of the component shall be no less than that used in the qualification test.

III-762 WHITE LIGHT INTENSITY MEASUREMENT

The white light intensity on the surface of the component shall be no greater than that used in the qualification test.

III-770 EXAMINATION

The qualification standard shall be placed on a carbon steel plate and examined in accordance with the procedure to be qualified and a standard procedure that has previously been demonstrated as suitable for use. The standard procedure may utilize a visible or fluorescent technique. The flaw indications shall be compared; if the

Table III-721
Requirements for an AC or HWDC Yoke Technique With Fluorescent Particles in an Undarkened Area

Requirement	Essential Variable	Nonessential Variable
Identification of surface configurations to be examined and product forms (e.g., base material or welded surface)	X	...
Surface condition requirement and preparation methods	X	...
Yoke manufacturer and model	X	...
Particle manufacturer and designation	X	...
Minimum and maximum pole separation	X	...
Identification of steps in performing the examination	X	...
Maximum white light intensity	X	...
Minimum black light intensity	X	...
Personnel qualification requirements	...	X
Reference to the procedure qualification records	...	X

indication obtained under the proposed conditions appears the same or better than that obtained under standard conditions, the proposed procedure shall be considered qualified for use.

III-777 INTERPRETATION

For interpretation, both black and white light intensity shall be measured with light meters.

III-790 DOCUMENTATION

III-791 EXAMINATION RECORD

For each examination, the information required in T-793 and the following information shall be recorded:

(a) qualification standard identification

(b) identification of the personnel performing and witnessing the qualification

(c) equipment and materials used

(d) illumination levels (white and black light)

(e) qualification results

MANDATORY APPENDIX IV QUALIFICATION OF ALTERNATE WAVELENGTH LIGHT SOURCES FOR EXCITATION OF FLUORESCENT PARTICLES

IV-710 SCOPE

This Appendix provides the methodology to qualify the performance of fluorescent particle examinations using alternate wavelength sources.

IV-720 GENERAL

Requirements of Article 7 apply unless modified by this Appendix.

IV-721 WRITTEN PROCEDURE REQUIREMENTS

IV-721.1 Requirements. The requirements of Table IV-721 apply to Written Procedure Requirements (T-721.1) and when specified by the referencing Code Section to Procedure Qualification (T-721.2).

IV-723 PROCEDURE DEMONSTRATION

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

IV-750 TECHNIQUE

IV-751 QUALIFICATION STANDARD

Slotted shim(s) 0.002 in. (0.05 mm) thick having 30% deep material removed as described in T-764.2(b) shall be used to qualify the alternate wavelength light source and specific particles. Shim(s) shall be tape sealed to a ferromagnetic object's surface and used as described in T-764.2(b) with the notch against the object's surface.

IV-752 FILTER GLASSES

If the alternative wavelength light source emits light in the visible portion of the spectrum (wavelength of 400 nm or longer), the examiner shall wear filter glasses that have been supplied by the manufacturer of the light source to block the reflected visible excitation light while transmitting the fluorescence of the particles.

IV-770 QUALIFICATION EXAMINATIONS

IV-771 BLACK LIGHT INTENSITY

The black light intensity on the examination surface shall be adjusted by varying the distance or power so that it has a minimum intensity of 1,000 μW/cm^2 and a maximum intensity of 1,100 μW/cm^2.

IV-772 EXAMINATION REQUIREMENTS

The examination parameters for the object chosen shall be determined by the rules of T-750 applicable to the object chosen and the method of magnetization. Any of the magnetizing techniques listed in T-751 may be used. The same indication(s) of the shim discontinuity(ies) shall be used for both black light and alternate wavelength light examinations.

Table IV-721
Requirements for Qualifying Alternate Wavelength Light Sources for Excitation of Specific Fluorescent Particles

Requirement	Essential Variable	Nonessential Variable
Particle manufacturer and designation	X	...
Carrier (water or oil); if oil, manufacturer and type designation	X	...
Alternate wavelength light source manufacturer and model	X	...
Alternate wavelength light source meter, manufacturer, and model	X	...
Filter glasses (if needed)	X	...
Minimum alternative wavelength light intensity	X	...
Qualification records	...	X

IV-772.1 Examination With Black Light. The qualification standard with the attached shim(s) shall be examined with the established parameters and specific particles in a darkened area with black light illumination. The resulting particle indication(s) shall be photographed.

IV-772.2 Examination With Alternate Wavelength Light. Using the same particle indication(s) examined in IV-772.1, switch to the alternate wavelength light source and adjust the light intensity by varying the distance or power, to establish particle indication(s) essentially the same as that (those) obtained with the black light above. The light intensity shall be measured with the alternative wavelength light meter. The resulting particle indication(s) shall be photographed using identical photographic techniques as used for the black light. However, camera lens filters appropriate for use with the alternate wavelength light source should be used for recording the indication(s), when required.

IV-773 QUALIFICATION OF ALTERNATE WAVELENGTH LIGHT SOURCE AND SPECIFIC PARTICLES

When the same particle indication(s) as achieved with black light can be obtained with the alternate wavelength light source, the alternate wavelength light source may be used for magnetic particle examinations. The alternate wavelength light source with at least the minimum intensity qualified shall be used with the specific particle designation employed in the qualification.

IV-790 DOCUMENTATION

IV-791 EXAMINATION RECORD

For each examination, the information required in T-793 and the following information shall be recorded:

(a) alternative wavelength light source, manufacturer, and model

(b) alternative wavelength light source meter, manufacturer, and model

(c) filter glasses, when necessary

(d) fluorescent particle manufacturer and designation

(e) qualification standard identification

(f) technique details

(g) identification of the personnel performing and witnessing the qualification

(h) equipment and materials used

(i) minimum alternate wavelength light intensity

(j) black light and alternative wavelength light qualification photos, exposure settings, and filters, if used

MANDATORY APPENDIX V
REQUIREMENTS FOR THE USE OF MAGNETIC RUBBER TECHNIQUES

V-710 SCOPE

This Appendix provides the methodology and equipment requirements applicable for performing magnetic particle examinations using magnetic rubber techniques in place of wet or dry magnetic particles. The principal applications for this technique are

(a) limited visual or mechanical accessibility, such as bolt holes

(b) coated surfaces

(c) complex shapes or poor surface conditions

(d) discontinuities that require magnification for detection and interpretation

(e) permanent record of the actual inspection

(19) V-720 GENERAL REQUIREMENTS

(a) Requirements. Requirements of Article 7 apply unless modified by this Appendix.

(b) Application. To accommodate the examination of a variety of surfaces, a liquid polymer containing ferromagnetic particles is applied to the surface instead of conventional dry or suspended wet particles. During the cure time, the application of magnetizing fields cause the particles to migrate and form patterns at discontinuities. The polymer cures forming an elastic solid (e.g., a rubber replica) with indications permanently fixed on its surface.

(19) V-721 WRITTEN PROCEDURE REQUIREMENTS

(a) Requirements. Magnetic rubber techniques shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table V-721. The written procedure shall establish a single value, or range of values, for each requirement.

(b) Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table V-721 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

V-730 EQUIPMENT

V-731 MAGNETIZING APPARATUS

A suitable means for producing the magnetic field orientation and strength in the part shall be employed, using direct or rectified current except where coatings are involved. Fields generated by alternating current electromagnetic yokes shall not be used except where nonmagnetic coatings are used on external surfaces. Gaussmeters or artificial shims shall be used for field strength and direction determination.

V-732 MAGNETIC RUBBER MATERIALS

The material shall be in the form of a vulcanizing polymer (rubber) liquid or semiliquid, containing ferromagnetic particles. The material shall be utilized at the temperature range as recommended by the manufacturer. When demonstration is required, the temperature shall be recorded.

V-733 MAGNETIC FIELD STRENGTH

A calibrated gaussmeter or artificial shims shall be used to determine the magnetic field strength and direction on surfaces to be examined. The gaussmeter device shall be equipped with both transverse and axial field probes. Dial or similar type calibrated meters of suitable range may be used, providing they are capable of making transverse and axial measurements. Values for G (kAm^{-1}) or the use of artificial shims shall be in accordance with T-764.

V-734 MAGNIFICATION

Replica viewing may be aided by the use of magnification.

V-740 MISCELLANEOUS REQUIREMENTS

V-741 SURFACE PREPARATION

(a) Prior to the magnetic particle examination, the surface(s) to be examined and adjacent areas within at least $\frac{1}{2}$ in. (13 mm) of the area of interest shall be dry and free of all dirt, oil, grease, paint, lint, scale and welding flux, and other extraneous material that could restrict particle movement and interfere with the examination by

Table V-721
Requirements for the Magnetic Rubber Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Magnetic Rubber Mix Formulations [Manufacturer's name(s) for material of various viscosities and recommended cure times]	X	...
Surface preparation	X	...
Magnetizing technique	X	...
Field strength	X	...
Nonmagnetic coating thickness greater than previously qualified	X	...
Minimum cure time as recommended by the manufacturer	X	...
Releasing agent	X	...
Temperature range as specified by the manufacturer	X	...
Performance demonstration, when required	X	...
Number of fields and directions to be applied and magnetizing time for each direction	X	...
Demagnetizing	...	X
Personnel qualification requirements	...	X
Reference to the procedure qualification records	...	X

preventing cure or extending the curing time. Nonmagnetic surface coatings need not be removed for techniques using an alternating current electromagnetic yoke.

(b) When nonmagnetic coatings are left on the part in the area being examined, it shall be demonstrated with an alternating current electromagnetic yoke that the indications can be detected through the existing maximum coating thickness per Article 7, Mandatory Appendix I.

V-742 TAPING AND DAMMING

Tape, putty, plugs, and other suitable means shall be used to form dams or encapsulations that will provide a reservoir or containment to hold the liquid or semi-liquid polymer in contact with the area of interest during magnetization and until curing is complete. The construction of the containment will depend on the geometry of the material and the area of interest. Some examples are as follows:

(a) Horizontal Through–holes. Place adhesive tape over one side of the hole, making a pinhole in the tape at the top of the hole for release of air during pouring. A cup, open on the top side and fabricated from heavy aluminum foil, may be attached with tape or putty to the opposite side of the hole to serve as a funnel during pouring of the liquid polymer.

(b) Flat Surface. Putty dams may be constructed around the area of interest to contain the liquid polymer after pouring.

(c) Inverted Surfaces. A putty reservoir may be placed beneath the examination area and pressure fill the area with liquid polymer allowing trapped air to escape by placing a small vent hole in the dam next to the area of interest. Inverted holes may be filled by pressure feeding the liquid polymer at the upper side of the dammed hole. Place a small tube, open at each end, next to the fill tube with one end at the same location as the end of the fill tube. Pressure feed until the polymer overflows from the second tube. Remove tubes when fill is completed and plug access holes.

V-743 RELEASE TREATMENT

Areas where the liquid polymer has been in contact with the examination or other surfaces may result in a temporary adhesion of the rubber. To avoid this condition, the area where the liquid polymer will be in contact shall be treated with a Teflon-type release agent prior to the application of the liquid polymer. The release treatment agent shall not contain silicones.

V-750 TECHNIQUES

V-751 TECHNIQUES

Magnetization techniques used are comparable to those described in T-750. Direct current electromagnetic yokes are the preferred magnetizing device.

V-752 APPLICATION OF MAGNETIC FIELD

Flaws are displayed more vividly when a discontinuity is oriented perpendicular to the magnetic lines of force. Magnetism shall be applied in a minimum of two or more directions, where two of the magnetic lines of force are approximately perpendicular to each other and at least one of the lines of force are perpendicular to suspected discontinuities.

V-760 CALIBRATION

V-764 MAGNETIC FIELD ADEQUACY AND DIRECTION

The field strength shall be measured using a gaussmeter. The area to be examined shall be checked in two directions by placing the gaussmeter probe in the hole or on the surface to be inspected and noting the field strength and direction of the magnetic field. Artificial flaw shims, as described in T-764.2(b), may also be used when accessibility allows, to determine the field strength and direction of magnetization using wet or dry particles.

V-770 EXAMINATION

V-773 APPLICATION OF LIQUID POLYMER-MAGNETIC PARTICLE MATERIAL

Following the initial steps of preparation, a freshly prepared polymer-magnetic particle mix shall be cast or molded into/onto the prepared area. The magnetic field, previously determined to have the required minimum field strength recommended by the polymer-particle manufacturer, shall be applied to the area of interest. A minimum of two fields 90 deg apart shall be maintained for an equal amount of time during the cure time of the liquid polymer-particle mix used. When more than two fields are to be applied, a minimum time in the first direction shall be allowed before magnetization in the next direction is applied and the same minimum time used for each subsequent magnetization. The cure time applied to each direction shall be based on the mix's cure time divided by the number of magnetic fields applied.

V-774 MOVEMENT DURING CURE

During the cure time of the liquid polymer-particle mix, movement of the item shall be avoided to ensure indications are not distorted.

V-776 REMOVAL OF REPLICAS

Replicas shall be removed as soon as practical after cure by careful use of a tool or compressed air. Additional time must be allowed if the polymer is not fully cured or sticks to the examination area.

V-780 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Following removal, the replicas shall be examined visually in order to detect any damage to the surface of the replica. When the area of interest shows damage or lack of fill or contact with the examination surface, the examination shall be repeated.

(c) When dimensional data is required, an illuminating-magnifying device capable of making measurements shall be used.

V-790 DOCUMENTATION

V-793 EXAMINATION RECORDS

For each examination, the following information shall be recorded:

(a) date of the examination

(b) procedure identification and revision

(c) magnetic rubber mix — manufacturer and identification

(d) examination personnel, if required by the referencing Code Section

(e) map or record of indications for evaluation, per T-792

(f) use, type and power of magnification

(g) material and thickness

(h) magnetic particle equipment and type of current

(i) gaussmeter; manufacturer, model, serial number, or artificial shims used

(j) field strength (if gaussmeter is used), duration and total time of application

(k) when more than two fields are applied, number and sequencing of the applications

(l) temperature

NONMANDATORY APPENDIX A MEASUREMENT OF TANGENTIAL FIELD STRENGTH WITH GAUSSMETERS

A-710 SCOPE

This Nonmandatory Appendix is used for the purpose of establishing procedures and equipment specifications for measuring the tangential applied magnetic field strength.

A-720 GENERAL REQUIREMENTS

Personnel qualification requirements shall be in accordance with Article 1.

Gaussmeters and related equipment shall be calibrated in accordance with T-763.

Definitions of terms used in this Appendix are in Article 1, Mandatory Appendix I, I-121.4, MT — Magnetic Particle.

A-730 EQUIPMENT

Gaussmeter having the capability of being set to read peak values of field intensity. The frequency response of the gaussmeter shall be at least 0 Hz to 300 Hz.

The Hall-Effect tangential field probe should be no larger than 0.2 in. (5 mm) by 0.2 in. (5 mm) and should have a maximum center location 0.2 in. (5 mm) from the part surface. Probe leads shall be shielded or twisted to prevent reading errors due to voltage induced during the large field changes encountered during magnetic particle examinations.

A-750 PROCEDURE

Care shall be exercised when measuring the tangential applied field strengths specified in T-764.2(c). The plane of the probe must be perpendicular to the surface of the part at the location of measurement to within 5 deg. This may be difficult to accomplish by hand orientation. A jig or fixture may be used to ensure this orientation is achieved and maintained.

The direction and magnitude of the tangential field on the part surface can be determined by placing the Hall-Effect tangential field probe on the part surface in the area of interest. The direction of the field can be determined during the application of the magnetizing field by rotating the tangential field probe while in contact with the part until the highest field reading is obtained on the Gaussmeter. The orientation of the probe, when the highest field is obtained, will indicate the field direction at that point. Gaussmeters cannot be used to determine the adequacy of magnetizing fields for multidirectional and coil magnetization techniques.

Once adequate field strength has been demonstrated with artificial flaw shims, Gaussmeter readings may be used at the location of shim attachment on identical parts or similar configurations to verify field intensity and direction.

A-790 DOCUMENTATION/RECORDS

Documentation should include the following:

(a) equipment model and probe description;

(b) sketch or drawing showing where measurements are made; and

(c) field intensity and direction of measurement.

ARTICLE 8
EDDY CURRENT EXAMINATION

(19) T-810 SCOPE

When specified by the referencing Code Section, the eddy current examination method and techniques described in this Article shall be used.

(a) This Article describes the techniques to be used when performing eddy current examinations on conductive-nonferromagnetic and coated ferromagnetic materials.

(b) The requirements of Article 1, General Requirements, also apply when eddy current examination, in accordance with Article 8, is required by a referencing Code Section.

(c) Definitions of terms for eddy current examination appear in Article 1, Mandatory Appendix I, I-121.5, ET — Electromagnetic (Eddy Current).

(d) Mandatory Appendix II, Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing, provides the requirements for bobbin coil multifrequency and multiparameter eddy current examination of installed nonferromagnetic heat exchanger tubing.

(e) Mandatory Appendix III, Eddy Current Examination on Coated Ferromagnetic Materials, provides eddy current requirements for eddy current examination on coated ferromagnetic materials.

(f) Mandatory Appendix IV, External Coil Eddy Current Examination of Tubular Products, provides the requirements for external coil eddy current examination of seamless copper, copper alloy, austenitic stainless steel, Ni-Cr-Fe alloy, and other nonferromagnetic tubular products.

(g) Mandatory Appendix V, Eddy Current Measurement of Nonconductive-Nonferromagnetic Coating Thickness on a Nonferromagnetic Metallic Material, provides the requirements for surface probe eddy current examination for measuring nonconductive-nonferromagnetic coating thicknesses.

(h) Mandatory Appendix VI, Eddy Current Detection and Measurement of Depth of Surface Discontinuities in Nonferromagnetic Metals With Surface Probes, provides the requirements for surface probe eddy current examination for detection of surface connected discontinuities and measuring their depth.

(i) Mandatory Appendix VII, Eddy Current Examination of Ferromagnetic and Nonferromagnetic Conductive Metals to Determine If Flaws Are Surface Connected, provides the requirements for eddy current examination with a surface probe to determine if flaws are surface connected in both ferromagnetic and nonferromagnetic metals.

(j) Mandatory Appendix VIII, Alternative Technique for Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing, Excluding Nuclear Steam Generator Tubing, provides the requirements for an alternative technique for bobbin coil multifrequency and multiparameter eddy current examination of installed nonferromagnetic heat exchanger tubing, excluding nuclear steam generator tubing.

(k) Mandatory Appendix IX, Eddy Current Array Examination of Ferromagnetic and Nonferromagnetic Materials for the Detection of Surface-Breaking Flaws, provides the requirements for eddy current array (ECA) surface probe examination of coated and noncoated ferromagnetic and nonferromagnetic materials for the detection of surface-breaking flaws.

(l) Mandatory Appendix X, Eddy Current Array Examination of Ferromagnetic and Nonferromagnetic Welds for the Detection of Surface-Breaking Flaws, provides the requirements for ECA surface probe examination of coated and noncoated ferromagnetic and nonferromagnetic welds for the detection of surface-breaking flaws.

MANDATORY APPENDIX II EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING (19)

II-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonferromagnetic heat exchanger tubing, when this Appendix is specified by the referencing Code Section.

II-820 GENERAL

This Appendix also provides the methodology for examining nonferromagnetic, heat exchanger tubing using the eddy current method and bobbin coil technique. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with a bobbin coil attached to a flexible shaft pulled through tubing manually or by a motorized device. Results are obtained by evaluating data acquired and recorded during scanning.

II-821 WRITTEN PROCEDURE REQUIREMENTS

II-821.1 Requirements. Eddy current examinations shall be conducted in accordance with a written procedure which shall contain, as a minimum, the requirements listed in Table II-821. The written procedure shall establish a single value, or range of values, for each requirement.

II-821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table II-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

II-822 PERSONNEL REQUIREMENTS

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with the requirements of this Appendix and the referencing Code Section.

II-830 EQUIPMENT

II-831 DATA ACQUISITION SYSTEM

II-831.1 Multifrequency-Multiparameter Equipment. The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(a) The outputs from the eddy current instrument shall provide phase and amplitude information.

(b) The eddy current instrument shall be capable of operating with bobbin coil probes in the differential mode or the absolute mode, or both.

(c) The eddy current system shall be capable of real time recording and playing back of examination data.

(d) The eddy current equipment shall be capable of detecting and recording dimensional changes, metallurgical changes and foreign material deposits, and responses from imperfections originating on either tube wall surface.

II-832 ANALOG DATA ACQUISITION SYSTEM

II-832.1 Analog Eddy Current Instrument.

(a) The frequency response of the outputs from the eddy current instrument shall be constant within 2% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed in./sec (mm/s).

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

(c) The frequency response of the instrument output shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-sec/mm) times maximum probe travel speed.

II-832.2 Magnetic Tape Recorder.

(a) The magnetic tape recorder used with the analog equipment shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

Table II-821
Requirements for an Eddy Current Examination Procedure

Requirements as Applicable	Essential Variable	Nonessential Variable
Tube material	X	...
Tube diameter and wall thickness	X	...
Mode of inspection — differential or absolute	X	...
Probe type and size	X	...
Length of probe cable and probe extension cables	X	...
Probe manufacturer, part number, and description	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Manufacturer and model of eddy current equipment	X	...
Scanning direction during data recording, i.e., push or pull	X	...
Scanning mode — manual, mechanized probe driver, remote controlled fixture	X	...
Fixture location verification	X	...
Identity of calibration reference standard(s)	X	...
Minimum digitization rate	X	...
Maximum scanning speed during data recording	X	...
Personnel requirements	...	X
Data recording equipment manufacturer and model	...	X
Scanning speed during insertion or retraction, no data recording	...	X
Side of application — inlet or outlet	...	X
Data analysis parameters	...	X
Tube numbering	...	X
Tube examination surface preparation	...	X

(b) The frequency response of the magnetic tape recorder outputs shall be constant within 10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

(c) Signal reproducibility from input to output shall be within 5%.

II-832.3 Strip Chart Recorder.

(a) Strip chart recorders used with analog equipment shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within 20% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

II-833 DIGITAL DATA ACQUISITION SYSTEM

II-833.1 Digital Eddy Current Instrument.

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (25 mm) of examined tubing, use dr = sr/ss, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed in in. per sec.

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-sec/mm) times maximum probe travel speed.

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-833.2 Digital Recording System.

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

II-834 BOBBIN COILS

II-834.1 General Requirements.

(a) Bobbin coils shall be able to detect artificial discontinuities in the calibration reference standard.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

II-835 DATA ANALYSIS SYSTEM

II-835.1 Basic System Requirements.

(a) The data analysis system shall be capable of displaying eddy current signal data from all test frequencies.

(b) The system shall have multiparameter mixing capability.

(c) The system shall be capable of maintaining the identification of each tube recorded.

(d) The system shall be capable of measuring phase angles in increments of one degree or less.

(e) The system shall be capable of measuring amplitudes to the nearest 0.1 volt.

II-836 ANALOG DATA ANALYSIS SYSTEM

II-836.1 Display. Eddy current signals shall be displayed as Lissajous patterns by use of an X-Y storage display oscilloscope or equivalent. The frequency response of the display device shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

II-836.2 Recording System.

(a) The magnetic tape recorder shall be capable of playing back the recorded data.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within 10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed in./sec (mm/s).

(c) Signal reproducibility input to output shall be within 5%.

II-837 DIGITAL DATA ANALYSIS SYSTEM

II-837.1 Display.

(a) The analysis display shall be capable of presenting recorded eddy current signal data and test information.

(b) The analysis system shall have a minimum resolution of 12 bits per data point.

(c) The Lissajous pattern display shall have a minimum resolution of 7 bits full scale.

(d) The strip chart display shall be selectable so either the X or Y component of any examination frequency or mixed frequencies can be displayed.

(e) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-837.2 Recording System.

(a) The recording system shall be capable of playing back all recorded eddy current signal data and test information.

(b) The recording system shall have a minimum resolution of 12 bits per data point.

II-838 HYBRID DATA ANALYSIS SYSTEM

(a) Individual elements of hybrid systems using both digital elements and some analog elements shall meet specific sections of II-830, as applicable.

(b) When analog to digital or digital to analog converters are used, the frequency response of the analog element outputs shall be constant within 5% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

II-840 REQUIREMENTS

II-841 RECORDING AND SENSITIVITY LEVEL

(a) The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

(b) The sensitivity for the differential bobbin coil technique shall be sufficient to produce a response from the through-wall hole(s) with a minimum vertical amplitude of 50% of the full Lissajous display height.

II-842 PROBE TRAVERSE SPEED

The traverse speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities. Minimum digitization rates must be maintained at all times.

II-843 FIXTURE LOCATION VERIFICATION

(a) The ability of the fixture to locate specific tubes shall be verified visually and recorded upon installation of the fixture and before relocating or removing the fixture. Independent position verification, e.g., specific landmark location, shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(b) When the performance of fixture location reveals that an error has occurred in the recording of probe verification location, the tubes examined since the previous location verification shall be reexamined.

II-844 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

II-860 CALIBRATION

II-861 EQUIPMENT CALIBRATION

II-861.1 Analog Equipment. The following shall be verified by annual calibration:

(a) the oscillator output frequency to the drive coil shall be within 5% of its indicated frequency

(b) the vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within 10% of the deflection of the input voltage

(c) the CRT vertical and horizontal trace alignment shall be within 2 deg of parallel to the graticule lines

(d) the ratio of the output voltage from the tape recorder shall be within 5% of the input voltage for each channel of the tape recorder

(e) the chart speed from the strip chart recorder shall be within 5% of the indicated value

(f) amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency

(g) the two output channels of the eddy current instrument shall be orthogonal within 3 deg at the examination frequency

II-861.2 Digital Equipment. Analog elements of digital equipment shall be calibrated in accordance with II-861.1. Digital elements need not be calibrated.

II-862 CALIBRATION REFERENCE STANDARDS

II-862.1 Calibration Reference Standard Requirements. Calibration reference standards shall conform to the following:

(a) Calibration reference standards shall be manufactured from tube(s) of the same material specification and nominal size as that to be examined in the vessel.

(b) Tubing calibration reference standard materials heat treated differently from the tubing to be examined may be used when signal responses from the discontinuities described in II-862.2 are demonstrated to the Inspector to be equivalent in both the calibration reference standard and tubing of the same heat treatment as the tubing to be examined.

(c) As an alternative to (a) and (b), calibration reference standards fabricated from UNS Alloy N06600 shall be manufactured from a length of tubing of the same material specification and same nominal size as that to be examined in the vessel.

(d) Artificial discontinuities in calibration reference standards shall be spaced axially so they can be differentiated from each other and from the ends of the tube. The as-built dimensions of the discontinuities and the applicable eddy current equipment response shall become part of the permanent record of the calibration reference standard.

(e) Each calibration reference standard shall be permanently identified with a serial number.

II-862.2 Calibration Reference Standards for Differential and Absolute Bobbin Coils.

(a) Calibration reference standards shall contain the following artificial discontinuities:

(1) One or four through-wall holes as follows:

(-a) A 0.052 in. (1.3 mm) diameter hole for tubing with diameters of 0.750 in. (19 mm) and less, or a 0.067 in. (1.70 mm) hole for tubing with diameters greater than 0.750 in. (19 mm).

(-b) Four holes spaced 90 deg apart in a single plane around the tube circumference, 0.026 in. (0.65 mm) diameter for tubing with diameters of 0.750 in. (19 mm) and less and 0.033 in. (0.83 mm) diameter for tubing with diameters greater than 0.750 in. (19 mm).

(2) A flat-bottom hole 0.109 in. (2.7 mm) diameter, 60% through the tube wall from the outer surface.

(3) Four flat-bottom holes 0.187 in. (5 mm) diameter, spaced 90 deg apart in a single plane around the tube circumference, 20% through the tube wall from the outer surface.

(b) The depth of the artificial discontinuities, at their center, shall be within 20% of the specified depth or 0.003 in. (0.08 mm), whichever is less. All other dimensions shall be within 0.003 in. (0.08 mm).

(c) All artificial discontinuities shall be sufficiently separated to avoid interference between signals, except for the holes specified in (a)(1)(-b) and (a)(3).

II-863 ANALOG SYSTEM SETUP AND ADJUSTMENT

II-863.1 Differential Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of 4 V from the four 20% flat-bottom holes or 6 V from the four through-wall drilled holes.

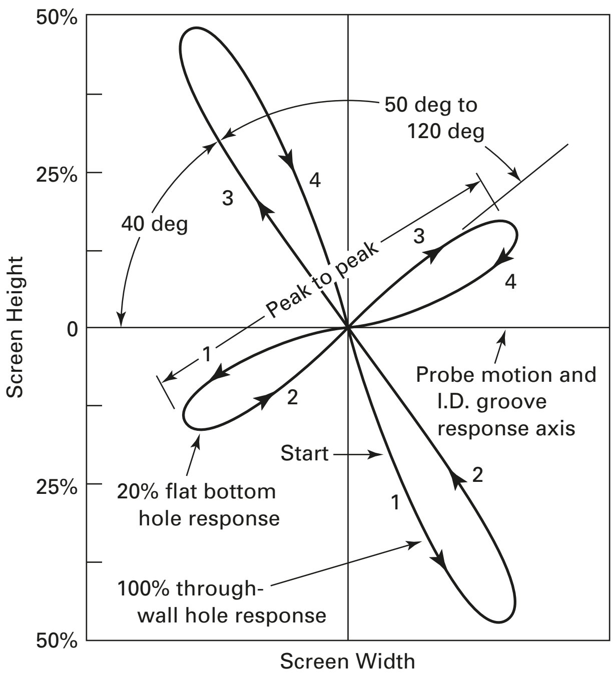
(b) The phase or rotation control shall be adjusted so the signal response due to the through-wall hole forms down and to the right first as the probe is withdrawn from the calibration reference standard holding the signal response from the probe motion horizontal. See Figure II-863.1.

(c) Withdraw the probe through the calibration reference standard at the nominal examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-863.2 Absolute Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal of 2 V from the four 20% flat-bottom holes or 3 V from the four through-wall drilled holes.

Figure II-863.1
Differential Technique Response From Calibration Reference Standard



(b) Adjust the phase or rotation control so that the signal response due to the through-wall hole forms up and to the left as the probe is withdrawn from the calibration reference standard holding the signal response from the probe motion horizontal. See Figure II-863.2.

(c) Withdraw the probe through the calibration reference standard at the nominal examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-864 DIGITAL SYSTEM OFF-LINE CALIBRATION

The eddy current examination data is digitized and recorded during scanning for off-line analysis and interpretation. The system setup of phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

II-864.1 System Calibration Verification.

(a) Calibration shall include the complete eddy current examination system. Any change of probe, extension cables, eddy current instrument, recording instruments, or any other parts of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(c) Should the system be found to be out of calibration (as defined in II-863), the equipment shall be recalibrated. The recalibration shall be noted on the recording. All tubes examined since the last valid calibration shall be reexamined.

II-870 EXAMINATION

Data shall be recorded as the probe traverses the tube.

II-880 EVALUATION

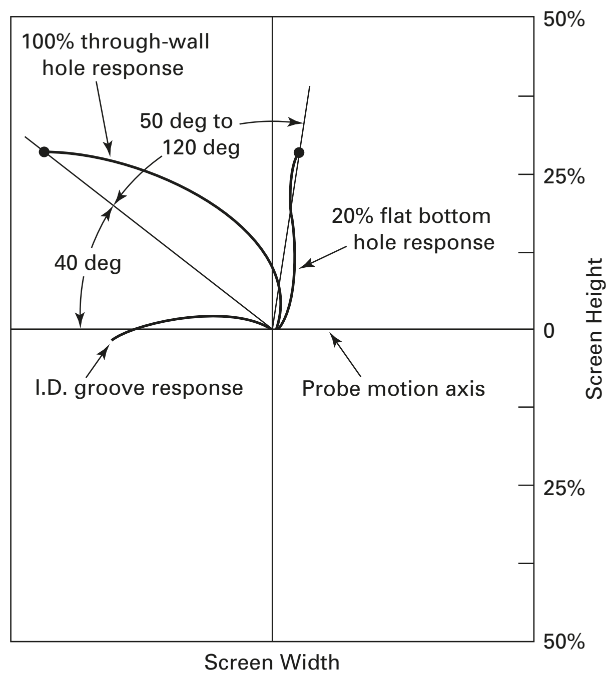
II-881 DATA EVALUATION

Data shall be evaluated in accordance with the requirements of this Appendix.

II-882 MEANS OF DETERMINING INDICATION DEPTH

For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have

Figure II-863.2
Absolute Technique Response From Calibration Reference Standard



been qualified. This shall be accomplished by using curves, tables, or software. Figure II-880 illustrates the relationship of phase angle versus flaw depth for a nonferromagnetic thin-walled tube examined at a frequency selected to optimize flaw resolution.

II-883 FREQUENCIES USED FOR DATA EVALUATION

All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

II-890 DOCUMENTATION

II-891 REPORTING

II-891.1 Criteria. Indications reported in accordance with the requirements of this Appendix shall be described in terms of the following information, as a minimum:

(a) location along the length of the tube and with respect to the support members

(b) depth of the indication through the tube wall, when required by this Appendix

(c) signal amplitude

(d) frequency or frequency mix from which the indication was evaluated

II-891.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of tube wall loss. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

II-891.3 Nonquantifiable Indications. A nonquantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

II-891.4 Support Members.

II-891.4.1 Location of Support Members. The location of support members used as reference points for the eddy current examination shall be verified by fabrication drawings or the use of a measurement technique.

II-892 RECORDS

II-892.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

(a) Owner

(b) plant site and unit

(c) heat exchanger identification

(d) data storage unit number

(e) date of examination

(f) serial number of the calibration standard

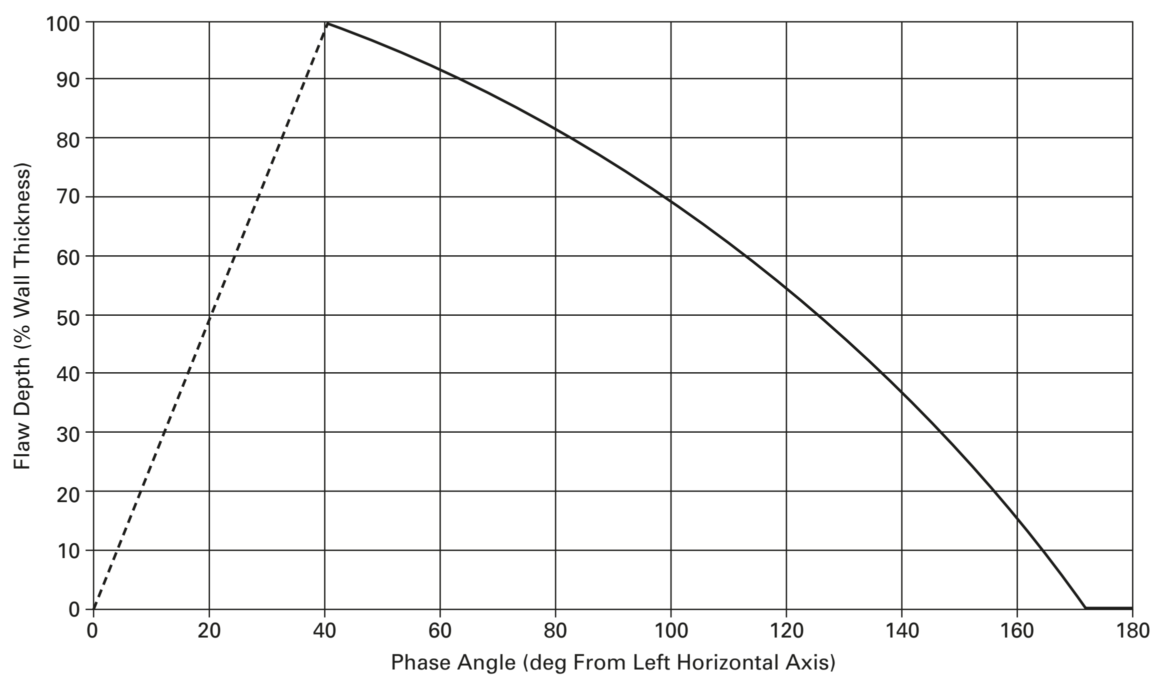
(g) operator's identification and certification level

(h) examination frequency or frequencies

(i) mode of operation including instrument sample rate, drive voltage, and gain settings

(j) lengths of probe and probe extension cables

Figure II-880
Flaw Depth as a Function of Phase Angle at 400 kHz [Ni–Cr–Fe 0.050 in. (1.24 mm) Wall Tube]



(k) size and type of probes
(l) probe manufacturer's name and manufacturer's part number or probe description and serial number
(m) eddy current instrument serial number
(n) probe scan direction during data acquisition
(o) application side — inlet or outlet
(p) slip ring serial number, as applicable
(q) procedure identification and revision

II-892.2 Tube Identification.

(a) Each tube examined shall be identified on the applicable unit of data storage and

(b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

II-892.3 Reporting.

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing Code Section. Procedures and equipment used shall be identified sufficiently to permit comparison of the examination results with new examination results run at a later date. This shall include initial calibration data for each eddy current examination system or part thereof.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

II-892.4 Record Retention. Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX III
EDDY CURRENT EXAMINATION ON COATED FERROMAGNETIC MATERIALS

III-810 SCOPE

(a) This Appendix provides the eddy current examination methodology and equipment requirements applicable for performing eddy current examination on coated ferromagnetic materials.

(b) Article 1, General Requirements, also applies when eddy current examination of coated ferromagnetic materials is required. Requirements for written procedures, as specified in Article 8, shall apply, as indicated.

(c) SD-1186, Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonferromagnetic Coatings Applied to a Ferromagnetic Base, may be used to develop a procedure for measuring the thickness of nonferromagnetic and conductive coatings.

III-820 GENERAL

III-821 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

III-822 WRITTEN PROCEDURE REQUIREMENTS

The requirements of IV-823 shall apply. The type of coating and maximum coating thickness also shall be essential variables.

III-823 PROCEDURE DEMONSTRATION

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with requirements of the referencing Code Section.

III-830 EQUIPMENT

The eddy current system shall include phase and amplitude display.

III-850 TECHNIQUE

The performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an eddy current technique may be used to measure the coating thickness. If the coating is conductive, a ferromagnetic coating thickness technique may be used in accordance with SD-1186. Coating thickness measurement shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (50 mm) maximum grid pattern over the area to be examined. The thickness shall be the mean of three separate readings within 0.250 in. (6 mm) of each intersection.

III-860 CALIBRATION

(a) A qualification specimen is required. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. If a conductive primer was used on the material to be examined, the primer thickness on the procedure qualification specimen shall be the maximum allowed on the examination surfaces by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification. The thickness of the coating or of the alternative plastic shim stock on the procedure qualification specimen shall be equal to or greater than the maximum coating thickness measured on the examination surface.

(b) The qualification specimen shall include at least one crack. The length of the crack open to the surface shall not exceed the allowable length for surface flaws. The maximum crack depth in the base metal shall be between 0.020 in. and 0.040 in. (0.5 mm and 1.0 mm). In addition, if the area of interest includes weld metal, a 0.020 in. (0.5 mm) maximum depth crack is required in an as-welded and coated surface typical of the welds to be examined. In lieu of a crack, a machined notch of 0.010 in. (0.25 mm) maximum width and 0.020 in. (0.5 mm) maximum depth may be used in the as-welded surface.

(c) Examine the qualification specimen first uncoated and then after coating to the maximum thickness to be qualified. Record the signal amplitudes from the qualification flaws.

(d) Using the maximum scanning speed, the maximum scan index, and the scan pattern specified by the procedure, the procedure shall be demonstrated to consistently detect the qualification flaws through the maximum coating thickness regardless of flaw orientation (e.g., perpendicular, parallel, or skewed to the scan direction). The signal amplitude from each qualification flaw in the

coated qualification specimen shall be at least 50% of the signal amplitude measured on the corresponding qualification flaw prior to coating.

III-870 EXAMINATION

(a) Prior to the examination, all loose, blistered, flaking, or peeling coating shall be removed from the examination area.

(b) When conducting examinations, areas of suspected flaw indications shall be confirmed by application of another surface or volumetric examination method. It may be necessary to remove the surface coating prior to performing the other examination.

III-890 DOCUMENTATION

III-891 EXAMINATION REPORT

The report of examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of rejectable indications

(e) identification of part or component examined

III-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX IV
EXTERNAL COIL EDDY CURRENT EXAMINATION OF TUBULAR PRODUCTS

(19) ## IV-810 SCOPE

This Appendix describes the method to be used when performing eddy current examinations of seamless copper, copper alloy, and other nonferromagnetic tubular products. The method conforms substantially with the following Standard listed in Article 26 and reproduced in Subsection B: SE-243, Standard Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes.

IV-820 GENERAL

IV-821 PERFORMANCE

Tubes may be examined at the finish size, after the final anneal or heat treatment, or at the finish size, prior to the final anneal or heat treatment, unless otherwise agreed upon between the supplier and the purchaser. The procedure shall be qualified by demonstrating detection of discontinuities of a size equal to or smaller than those in the reference specimen described in IV-833. Indications equal to or greater than those considered reportable by the procedure shall be processed in accordance with IV-880.

IV-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

IV-823 WRITTEN PROCEDURE REQUIREMENTS

IV-823.1 Requirements. Eddy current examinations shall be performed in accordance with a written procedure, which shall contain, as a minimum, the requirements listed in Table IV-823. The written procedure shall establish a single value, or range of values, for each requirement.

IV-823.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table IV-823 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

IV-830 EQUIPMENT

Equipment shall consist of electronic apparatus capable of energizing the test coil or probes with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic properties of the material. Output produced by this equipment may be processed so as to actuate signaling devices and/or to record examination data.

IV-831 TEST COILS AND PROBES

Test coils or probes shall be capable of inducing alternating currents into the material and sensing changes in the electromagnetic characteristics of the material. Test coils should be selected to provide the highest practical fill factor.

Table IV-823
Requirements of an External Coil Eddy Current Examination Procedure

Requirements (as Applicable)	Essential Variable	Nonessential Variable
Frequency(ies)	X	...
Mode (differential/absolute)	X	...
Minimum fill factor	X	...
Probe type	X	...
Maximum scanning speed during data recording	X	...
Material being examined	X	...
Material size/dimensions	X	...
Reference standard	X	...
Equipment manufacturer/model	X	...
Data recording equipment	X	...
Cabling (type and length)	X	...
Acquisition software	X	...
Analysis software	X	...
Scanning technique	...	X
Scanning equipment/fixtures	...	X
Tube scanning surface preparation	...	X

IV-832 SCANNERS

Equipment used should be designed to maintain the material concentric within the coil, or to keep the probe centered within the tube and to minimize vibration during scanning. Maximum scanning speeds shall be based on the equipment's data acquisition frequency response or digitizing rate, as applicable.

IV-833 REFERENCE SPECIMEN

The reference specimen material shall be processed in the same manner as the product being examined. It shall be the same nominal size and material type (chemical composition and product form) as the tube being examined. Ideally, the specimen should be a part of the material being examined. Unless specified in the referencing Code Section, the reference discontinuities shall be transverse notches or drilled holes as described in Standard Practice SE-243, Section 8, Reference Standards.

IV-850 TECHNIQUE

Specific techniques may include special probe or coil designs, electronics, calibration standards, analytical algorithms and/or display software. Techniques, such as channel mixes, may be used as necessary to suppress signals produced at the ends of tubes. Such techniques shall be in accordance with requirements of the referencing Code Section.

IV-860 CALIBRATION

IV-861 PERFORMANCE VERIFICATION

Performance of the examination equipment shall be verified by the use of the reference specimen as follows:

(a) As specified in the written procedure

(1) at the beginning of each production run of a given diameter and thickness of a given material

(2) at the end of the production run

(3) at any time that malfunctioning is suspected

(b) If, during calibration or verification, it is determined that the examination equipment is not functioning properly, all of the product tested since the last calibration or verification shall be reexamined.

(c) When requalification of the written procedure as required in IV-823.2.

IV-862 CALIBRATION OF EQUIPMENT

(a) Frequency of Calibration. Eddy current instrumentation shall be calibrated at least once a year, or whenever the equipment has been subjected to a major electronic repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to use.

(b) Documentation. A tag or other form of documentation shall be attached to the eddy current equipment with dates of the calibration and calibration due date.

IV-870 EXAMINATION

Tubes are examined by passing through an encircling coil, or past a probe coil with the apparatus set up in accordance with the written procedure. Signals produced by the examination are processed and evaluated. Data may be recorded for post-examination analysis or stored for archival purposes in accordance with the procedure. Outputs resulting from the evaluation may be used to mark and/or separate tubes.

IV-880 EVALUATION

Evaluation of examination results for acceptance shall be as specified in the written procedure and in accordance with the referencing Code Section.

IV-890 DOCUMENTATION

IV-891 EXAMINATION REPORTS

A report of the examination shall contain the following information:

(a) tube material specification, diameter, and wall thickness condition

(b) coil or probe manufacturer, size and type

(c) mode of operation (absolute, differential, etc.)

(d) examination frequency or frequencies

(e) manufacturer, model, and serial number of eddy current equipment

(f) scanning speed

(g) procedure identification and revision

(h) calibration standard and serial number

(i) identity of examination personnel, and, when required by the referencing Code Section, qualification level

(j) date of examination

(k) list of acceptable material

(l) date of procedure qualification

(m) results of procedure requalification (as applicable)

IV-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX V EDDY CURRENT MEASUREMENT OF NONCONDUCTIVE-NONFERROMAGNETIC COATING THICKNESS ON A NONFERROMAGNETIC METALLIC MATERIAL

V-810 SCOPE

This Appendix provides requirements for absolute surface probe measurement of nonconductive-nonferromagnetic coating thickness on a nonferromagnetic metallic material.

V-820 GENERAL

This Appendix provides a technique for measuring nonconductive-nonferromagnetic coating thicknesses on a nonferromagnetic metallic substrate. The measurements are made with a surface probe with the lift-off calibrated for thickness from the surface of the test material. Various numbers of thickness measurements can be taken as the probe's spacing from the surface is measured. Measurements can be made with various types of instruments.

V-821 WRITTEN PROCEDURE REQUIREMENTS

V-821.1 Requirements. Eddy current examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table V-821. The written procedure shall establish a single value, or range of values, for each requirement.

V-821.2 Procedure Qualification/Technique Validation. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table V-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement, identified as a nonessential variable, does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

V-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

V-823 PROCEDURE/TECHNIQUE DEMONSTRATION

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

V-830 EQUIPMENT

The eddy current instrument may have a storage type display for phase and amplitude or it may contain an analog or digital meter. The frequency range of the instrument shall be adequate for the material and the coating thickness range.

Table V-821
Requirements of an Eddy Current Examination Procedure for the Measurement of Nonconductive-Nonferromagnetic Coating Thickness on a Metallic Material

Requirement	Essential Variable	Nonessential Variable
Examination frequency	X	...
Absolute mode	X	...
Size and probe type(s), manufacturer's name and description	X	...
Substrate material	X	...
Equipment manufacturer/model	X	...
Cabling (type and length)	X	...
Nonconductive calibration material (nonconductive shims)	...	X
Personnel qualification requirements unique to this technique	...	X
Reference to the procedure qualification records	...	X
Examination surface preparation	...	X

V-831 PROBES

The eddy current absolute probe shall be capable of inducing alternating currents into the material and sensing changes in the separation (lift-off) between the contact surface of the probe and the substrate material.

V-850 TECHNIQUE

A single frequency technique shall be used with a suitable calibration material such as nonconductive shim(s), paper, or other nonconductive nonferromagnetic material. The shims or other material thicknesses shall be used to correlate a position on the impedance plane or meter reading with the nonconductive material thicknesses and the no thickness position or reading when the probe is against the bare metal. If the thickness measurement is used only to assure a minimum coating thickness, then only a specimen representing the minimum thickness need be used.

V-860 CALIBRATION

The probe frequency and gain settings shall be selected to provide a suitable and repeatable examination. The probe shall be nulled on the bare metal.

(a) Impedance Plane Displays. For instruments with impedance plane displays, gains on the vertical and horizontal axes shall be the same value. The phase or rotation control and the gain settings shall be adjusted so that the bare metal (null) and the air point are located at diagonally opposite corners of the display. A typical coating thickness calibration curve is illustrated in Figure V-860.

(b) Meter Displays. For instruments with analog meter displays, the phase and gain controls shall be used to provide near full scale deflection between the bare metal and maximum coating thickness.

(c) All Instruments. For all instruments, the difference in meter readings or thickness positions on the screen shall be adequate to resolve a 10% change in the maximum thickness.

(d) Calibration Data. The screen positions or meter readings and the shim thicknesses shall be recorded along with the bare metal position or meter reading.

(e) Verification of Calibration. Calibration readings shall be verified every two hours. If, during recalibration, a reading representing a coating thickness change greater than ±10% from the prior calibration is observed, examinations made after the prior calibration shall be repeated.

V-870 EXAMINATION

Coating thickness measurements shall be taken at individual points as indicated in the referencing Code Section. If it is desired to measure the minimum coating thickness or maximum coating thickness on a surface, a suitable grid pattern shall be established and measurements shall be taken at the intersections of the grid pattern. Measurements shall be recorded.

V-880 EVALUATION

Coating thicknesses shall be compared with the acceptance standards of the referencing Code Section.

V-890 DOCUMENTATION

V-891 EXAMINATION REPORT

The report of the examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level

(c) date of examination

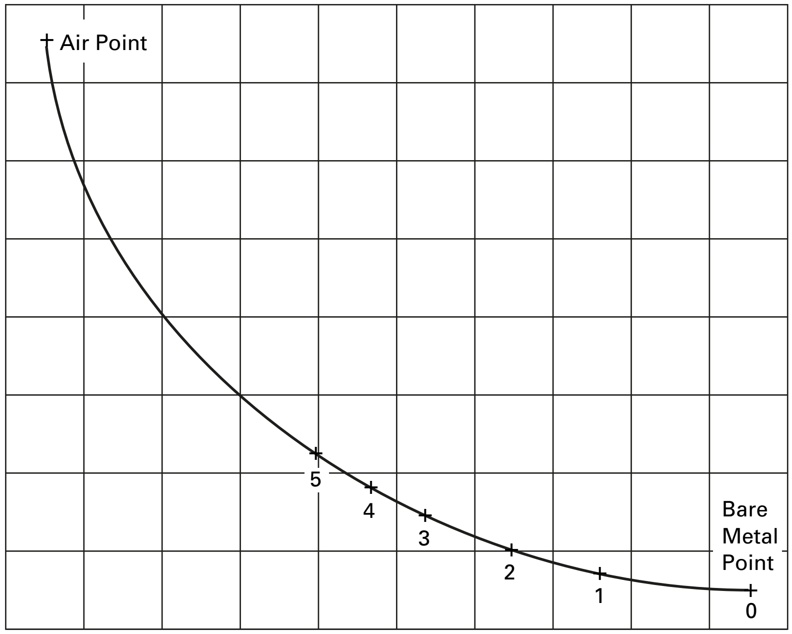
(d) results of examination and related sketches or maps of thickness measurements

(e) identification of part or component examined

V-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

Figure V-860
Typical Lift-off Calibration Curve for Coating Thickness Showing Thickness Calibration Points Along the Curve



MANDATORY APPENDIX VI
EDDY CURRENT DETECTION AND MEASUREMENT OF DEPTH OF SURFACE DISCONTINUITIES IN NONFERROMAGNETIC METALS WITH SURFACE PROBES

VI-810 SCOPE

This Appendix provides the requirements for the detection and measurement of depth for surface discontinuities in nonferromagnetic-metallic materials using an absolute surface probe eddy current technique.

VI-820 GENERAL

This Appendix provides a technique for the detection and depth measurement of cracks and other surface discontinuities in nonferromagnetic metal components. An absolute surface probe containing a single excitation coil is scanned over the surface of the examination object. When a surface discontinuity is encountered by the magnetic field of the probe, eddy currents generated in the material change their flow and provide a different magnetic field in opposition to the probe's magnetic field. Changes in the eddy current's magnetic field and the probe's magnetic field are sensed by the instrument and are presented on the instrument's impedance plane display. These instruments generally have capability for retaining the signal on the instrument's display where any discontinuity signal can be measured and compared to the calibration data.

VI-821 WRITTEN PROCEDURE REQUIREMENTS

VI-821.1 Requirements. Eddy current examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table VI-821. The written procedure shall establish a single value, or range of values, for each requirement.

VI-821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table VI-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

VI-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

VI-823 PROCEDURE/TECHNIQUE DEMONSTRATION

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

Table VI-821
Requirements of an Eddy Current Examination Procedure for the Detection and Measurement of Depth for Surface Discontinuities in Nonferromagnetic Metallic Materials

Requirement	Essential Variable	Nonessential Variable
Examination frequency	X	...
Size and probe type(s), manufacturer's name and description	X	...
Material	X	...
Equipment manufacturer/model	X	...
Cabling (type and length)	X	...
Reference specimen and notch depths	X	...
Personnel qualification, when required by the referencing Code Section	X	...
Personnel qualification requirements unique to this technique	...	X
Reference to the procedure qualification records	...	X
Examination surface preparation	...	X

VI-830 EQUIPMENT

The eddy current instrument may have a storage type display for phase and amplitude on an impedance plane. The frequency range of the instrument shall be adequate to provide for a suitable depth of penetration for the material under examination.

VI-831 PROBES

The eddy current absolute probe shall be capable of inducing alternating currents into the material and sensing changes in the depth of the notches in the reference specimen. The probe and instrument at the frequency to be used in the examination shall provide a signal amplitude for the smallest reference notch of a minimum of 10% full screen height (FSH). With the same gain setting for the smallest notch, the signal amplitude on the largest notch shall be a minimum of 50% FSH. If the amplitudes of the signals cannot be established as stated, other probe impedances or geometries (windings, diameters, etc.) shall be used.

VI-832 REFERENCE SPECIMEN

A reference specimen shall be constructed of the same alloy as the material under examination. Minimum dimensions of the reference specimen shall be 2 in. (50 mm) by 4 in. (100 mm) and shall contain a minimum of two notches. Notch length shall be a minimum of 0.25 in. (6 mm) and notch depth shall be the minimum to be measured and the maximum depth allowed. If smaller length notches are required to be detected by the referencing Code Section, the reference specimen shall contain a smaller length notch meeting the referencing Code requirements. The depth shall have a tolerance of +10% and −20% of the required dimensions. A typical reference specimen for measuring flaw depths in the range of 0.01 in. (0.25 mm) through 0.04 in. (1 mm) is shown in Figure VI-832.

When curvature of the examination object in the area of interest is not flat and affects the lift-off signal, a reference specimen representing that particular geometry with the applicable notches shall be used.

VI-850 TECHNIQUE

A single frequency technique shall be used. The frequency shall be selected to result in an impedance plane presentation that will result in a 90 deg phase shift between the lift-off signal and the flaw signals. The resulting signals will be displayed using an impedance plane presentation with one axis representing the lift-off signal and the other axis representing the reference notch and flaw signal responses. The gain control on each axis displaying the flaw signals shall be adjusted to present amplitude for the flaw signal from the deepest notch to be at least 50% of the vertical or horizontal display it is presented on. Typical responses of the calibrated instrument are shown in Figure VI-850. Note that the display may be rotated to show these indications in accordance with the procedure. Typically, the gain setting on the axis displaying the discontinuity signal will have a gain setting higher than the axis displaying lift-off. Discontinuity indications will be mostly vertical or horizontal (at 90 deg to lift-off). Any surface discontinuities in the examination specimen would provide similar indications.

VI-860 CALIBRATION

The probe frequency and gain settings shall be selected to provide a suitable depth of penetration within the material so that the depth of the deepest notch is distinguishable from the next smaller notch. The gain settings on the vertical and horizontal axis shall be set so that there is a dB difference with the discontinuity depth gain being higher. The probe shall be nulled on the bare metal away from the notches. The X-Y position of the null point shall be placed on one corner of the screen. The phase or rotation control shall be adjusted so that when the probe is lifted off the metal surface, the display point travels at 90 deg to the discontinuity depth. Increase the vertical or horizontal gain, as applicable, if the smallest indication or the largest indication from the notches do not make 10% or 50% FSH, respectively. Maximum response from the notches is achieved when the probe is scanned perpendicular to the notch and centered on the notch. Differences in the vertical and horizontal gain may have to be adjusted. The screen indication lengths from the baseline (lift-off line) for each of the notch depths shall be recorded.

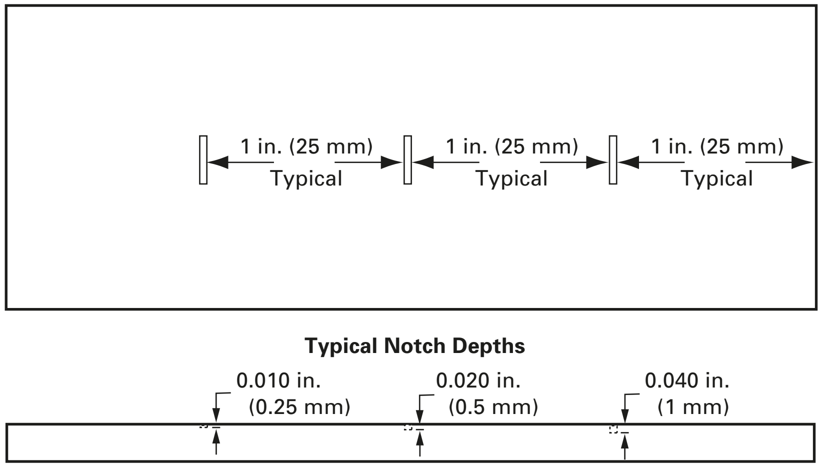
VI-870 EXAMINATION

The area of interest shall be scanned with overlap on the next scan to include at least 10% of the probe diameter. If the direction of suspected discontinuities are known, the scan direction shall be perpendicular to the long axis of the discontinuity. The object shall be scanned in two directions, 90 deg to each other. During the examination, the maximum scanning speed and lift-off distance shall not be greater than those used for calibration.

VI-880 EVALUATION

The discontinuity shall be scanned perpendicular to its long axis to determine its maximum depth location and value. The maximum depth of any discontinuity detected shall be compared with the appropriate response of the reference specimen as specified in the referencing Code Section.

Figure VI-832
Reference Specimen



GENERAL NOTES:
(a) Typical notch dimensions are 0.25 in. (6 mm) length × 0.010 in. (0.25 mm) width.
(b) Tolerances on notch dimensions are ±10% for length and width, and +10% and −20% for depth.

VI-890 DOCUMENTATION

VI-891 EXAMINATION REPORT

The report of the examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of indications exceeding acceptance standard

(e) identification of part or component examined

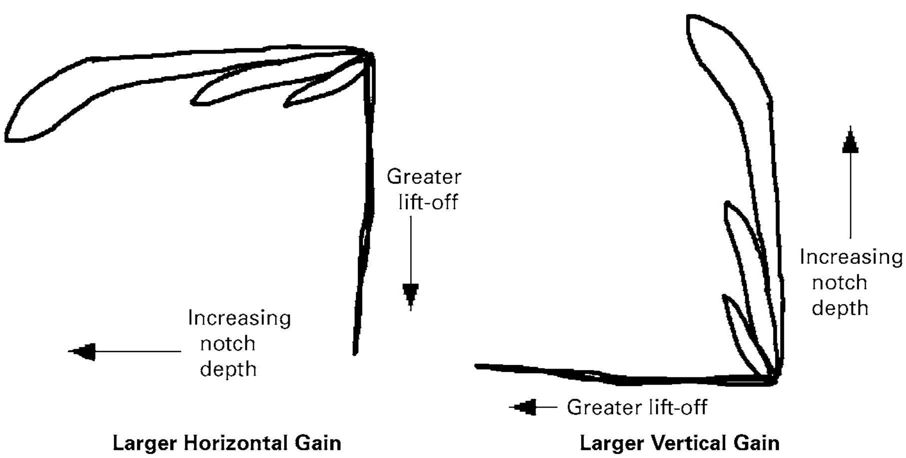
(f) identification of reference specimen

(g) calibration results, minimum and maximum discontinuity depth measured

VI-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

Figure VI-850
Impedance Plane Representations of Indications From Figure VI-832



MANDATORY APPENDIX VII EDDY CURRENT EXAMINATION OF FERROMAGNETIC AND NONFERROMAGNETIC CONDUCTIVE METALS TO DETERMINE IF FLAWS ARE SURFACE CONNECTED

VII-810 SCOPE

This Appendix provides the requirements for using an eddy current examination (ET) procedure to determine if flaws are surface connected (i.e., open to the surface being examined). With appropriate selection of parameters, the method is applicable to both ferromagnetic and nonferromagnetic conductive metals.

VII-820 GENERAL

VII-821 PERFORMANCE

This Appendix provides requirements for the evaluation of flaws, detected by other nondestructive examinations, utilizing a surface probe operating at a suitable test frequency or combination of frequencies. The resultant phase and amplitude responses are used to determine if flaws are surface connected.

VII-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix or the referencing Code Section.

VII-823 WRITTEN PROCEDURE REQUIREMENTS

VII-823.1 Requirements. Eddy current examinations shall be performed in accordance with a written procedure, which shall contain, as a minimum, the requirements listed in Table VII-823. The written procedure shall establish a single value or range of values, for each requirement.

VII-823.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table VII-823 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of or an addendum to the written procedure.

VII-830 EQUIPMENT (19)

VII-831 SYSTEM DESCRIPTION

The eddy current system shall consist of an eddy current instrument, surface probe, and cable connecting the instrument and the probe.

VII-832 SURFACE PROBES

The eddy current probes shall be either differential or absolute type. They shall be capable of inducing alternating currents in the material being examined and be capable of sensing changes in the resultant electromagnetic field.

VII-833 CABLES

Cables connecting the eddy current instrument and probes shall be designed and assembled to operate with these components.

Table VII-823
Requirements of an Eddy Current Surface Examination Procedure

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Frequencies	X	...
Mode (differential/absolute)	X	...
Probe type	X	...
Maximum scanning speed	X	...
Material being examined	X	...
Material surface condition	X	...
Reference specimen material and simulated flaws	X	...
ET instrument manufacturer/ model	X	...
Data presentation — display	X	...
Cabling (type and length)	X	...
Use of saturation	X	...
Analysis method	X	...
Scanning technique	...	X
Surface preparation	...	X

VII-834 INSTRUMENTATION

The eddy current instrument shall be capable of driving the probes selected for this examination with alternating current over a suitable range of frequencies. The eddy current instrument shall be capable of sensing and displaying differences in phase and amplitude correlated to the depth of discontinuities. The instrument shall be capable of operating in either the absolute or differential mode. The persistence shall be adjusted to display the phase and amplitude responses of the reference specimen notches and flaws in the material under examination.

VII-835 REFERENCE SPECIMEN

The reference specimen shall be constructed of the same alloy and product form as the material being examined. The reference specimen shall be as specified in Figure VII-835. Calibration references consist of two surface-connected notches and two bridged notches, representing both surface-connected and subsurface flaws.

The specimen shall be a minimum of 5.0 in. (125 mm) long, 1.5 in. (38 mm) wide, and $^1/_4$ in. (6 mm) thick. Additional notches and bridged notches may be added and block lengthened when additional information or higher precision is required. Surface conditions and finish of both the reference specimen and the material being examined shall be similar.

VII-850 TECHNIQUE

A single or multiple frequency technique may be used. The frequency(s) shall be selected to result in an impedance plane presentation of 90 deg to 180 deg phase shift between the surface and subsurface notch indications.

VII-860 CALIBRATION

VII-861 GENERAL

The probe frequency(s) and gain settings shall be selected to provide a suitable phase spread while providing sufficient penetration to ensure that the shallowest subsurface bridged notch indication is detected. Display gain of the vertical and horizontal axis shall be set to provide equal signal response. The ET instrument shall be adjusted to rotate the phase for the lift-off response to be positioned at the 270 deg horizontal plane. Scanning shall be conducted perpendicular to the length of the notches. The gain shall be set to display the 0.020 in. (0.5 mm) deep surface notch at 100% full screen height. At this gain setting, the 0.010 in. (0.24 mm) deep surface notch should be displayed at approximately 25% full screen height. The gain settings for these two reference notches may be accomplished on separate frequencies. Balancing the instrument will be conducted with the probe situated on the space between notches. Scanning speed shall be adjusted to allow the display to be formed for evaluation. The persistence of the screen shall be adjusted to allow a comparison of the responses from each notch. The screen shall be cleared to prevent the display to become overloaded. The presentation shall be balanced prior to making initial and final adjustments of phase and amplitude. Responses in terms of amplitude and phase angle resulting from scanning the surface notches and notch bridges shall be recorded.

VII-862 CALIBRATION RESPONSE

Typical responses from carbon steel and stainless steel calibration specimens are shown in Figure VII-862. Note that responses from ferromagnetic materials and nonferromagnetic materials provide significantly different displays.

VII-870 EXAMINATION

The flaw of interest shall be scanned with an overlap on the adjacent scan to include approximately 50% of the probe diameter. Scanning shall be conducted perpendicular to the flaw length. The identity of the flaw will be determined from the phase and amplitude of the displayed response. The phase and amplitude of flaws and their location will be recorded. During the examination the maximum scanning speed and lift-off distance shall not be greater than those used for calibration. The surface finish of areas scanned shall be comparable to the reference specimen.

VII-880 EVALUATION

Discrimination of surface-connected flaw responses from those of subsurface flaws shall be determined by comparable phase and amplitude responses obtained from similar surface-connected notches and subsurface, bridged notches contained in the reference specimen.

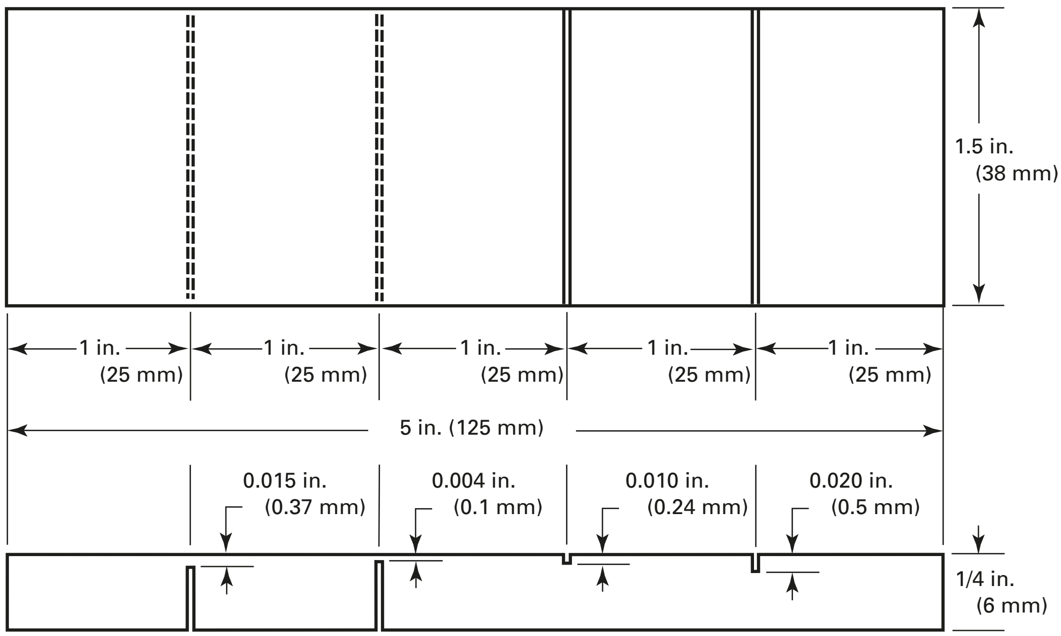
VII-890 DOCUMENTATION

VII-891 EXAMINATION REPORT

The report of the examination shall contain the following information:

(a) procedure identification and revision
(b) identification of examination personnel
(c) qualification of personnel, when required by the referencing Code Section
(d) date of examination
(e) identification of component or material examined
(f) scan plan including frequency(s) and gain
(g) flaw identity (e.g., surface connected or not surface connected)
(h) identification and drawing of reference calibration specimen
(i) calibration results (display) showing the indications of the bridged (subsurface) notches and surface notches detected

Figure VII-835
Eddy Current Reference Specimen



GENERAL NOTES:
(a) Drawing not to scale.
(b) Typical notch length may vary from 1 in. (25 mm) to full block width. Full width notches will require welding at the ends or filling the notch with epoxy to prevent block breakage.
(c) Maximum notch widths 0.010 in. (25 mm).
(d) Tolerance on notch bottoms +0/−10% from the examination surface.
(e) Block length, width, and thickness are as shown.
(f) Notch spacing and distance from ends of block are as shown.

(j) ET equipment manufacturer, model, type, and serial number

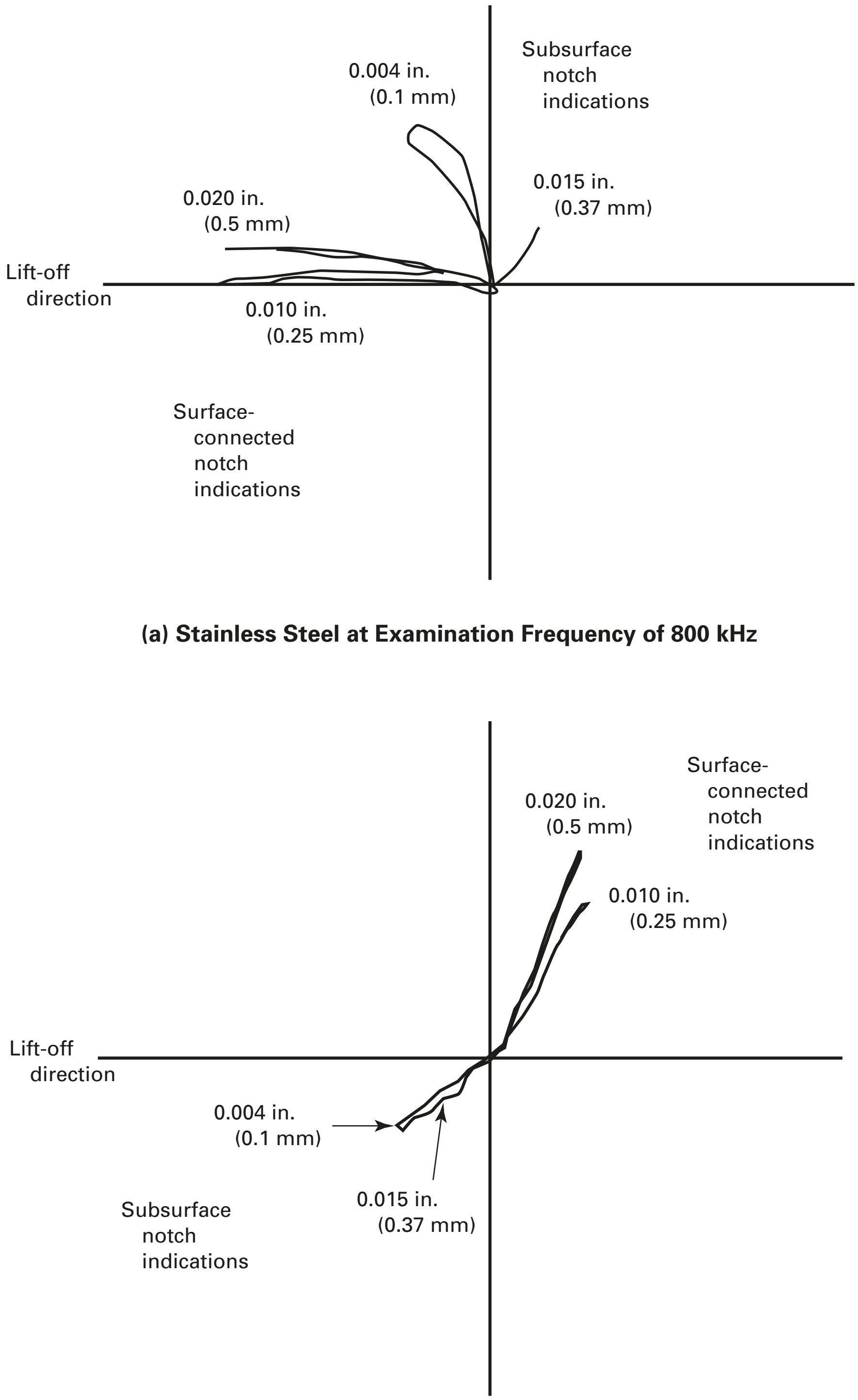
(k) probe manufacturer, model, type, and serial number

(l) extension cable, if used, manufacturer, type, and length

VII-892 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

Figure VII-862
Impedance Plane Responses for Stainless Steel and Carbon Steel Reference Specimens



(a) Stainless Steel at Examination Frequency of 800 kHz

(b) Carbon Steel at Examination Frequency of 800 kHz

(19)

MANDATORY APPENDIX VIII
ALTERNATIVE TECHNIQUE FOR EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING, EXCLUDING NUCLEAR STEAM GENERATOR TUBING

VIII-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonferromagnetic heat exchanger tubing, excluding nuclear steam generator tubing, when this Appendix is specified by the referencing Code Section.

VIII-820 GENERAL

This Appendix also provides the technique requirements for examining nonferromagnetic heat exchanger tubing using the electromagnetic method known as near field eddy current testing (the coil that generates the magnetic field also senses changes in the magnetic field). The method may employ one or more bobbin wound coils. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with the bobbin coil(s) attached to a flexible shaft pulled through tubing manually or by a motorized device. Results are obtained by evaluating data acquired and recorded during scanning. This Appendix does not address tubing with enhanced heat transfer surfaces or saturation eddy current testing.

VIII-821 WRITTEN PROCEDURE REQUIREMENTS

VIII-821.1 Requirements. Eddy current examinations shall be conducted in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table VIII-821. The written procedure shall establish a single value, or range of values, for each requirement.

VIII-821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table VIII-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

VIII-821.3 Personnel Requirements. The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of the referencing Code Section.

VIII-830 EQUIPMENT

VIII-831 DATA ACQUISITION SYSTEM

VIII-831.1 Multifrequency-Multiparameter Equipment. The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(a) The outputs from the eddy current instrument shall provide phase and amplitude information.

(b) The eddy current instrument shall be capable of operating with bobbin coil probes in the differential mode or the absolute mode, or both.

(c) The eddy current system shall be capable of real time recording.

(d) The eddy current equipment shall be capable of sensing and recording discontinuities, dimensional changes, resistivity/conductivity changes, conductive/magnetic deposits, and responses from imperfections originating on either tube wall surface.

VIII-832 ANALOG DATA ACQUISITION SYSTEM

VIII-832.1 Analog Eddy Current Instrument.

(a) The frequency response of the outputs from the eddy current instrument shall be constant within 2% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

VIII-832.2 Magnetic Tape Recorder.

(a) The magnetic tape recorder used with the analog equipment shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

(19)

Table VIII-821
Requirements for an Eddy Current Examination Procedure

Requirements (as Applicable)	Essential Variable	Nonessential Variable
Tube material, size (outside diameter), and wall thickness	X	...
Mode of inspection — differential and/or absolute	X	...
Probe type and size(s)	X	...
Probe manufacturer, part or serial number, and description	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Manufacturer and model of eddy current equipment	X	...
Maximum scanning speed	X	...
Scanning mode — manual, mechanized probe driver, remote controlled fixture	X	...
Identity of calibration reference standard(s) including drawing	X	...
Minimum digitization rate/samples per second	X	...
Procedure qualification	X	...
Personnel qualifications	...	X
Data recording equipment manufacturer and model	...	X
Data analysis parameters	...	X
Tube numbering	...	X
Tube examination surface preparation	...	X
Scanning equipment, extension cable, and fixtures	...	X

(b) The frequency response of the magnetic tape recorder outputs shall be constant within 10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

(c) Signal reproducibility from input to output shall be within 5%.

VIII-832.3 Strip Chart Recorder.

(a) Strip chart recorders used with analog equipment shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within 20% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

VIII-833 DIGITAL DATA ACQUISITION SYSTEM

VIII-833.1 Digital Eddy Current Instrument.

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (1.2 samples per mm) of examined tubing, use dr = sr/ss, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed [in./sec (mm/sec)].

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern as shown in Figure VIII-864.1.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

VIII-833.2 Digital Recording System.

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

VIII-834 BOBBIN COILS

VIII-834.1 General Requirements.

(a) Bobbin coils shall be able to detect artificial discontinuities in the calibration reference standard.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

(c) The probe fill factor [(probe diameter)^2/(tube inside diameter)^2 × 100] shall be a minimum of 80%.

(d) If the 80% fill factor cannot be achieved due to denting, corrosion, or other conditions, a minimum fill factor of 60% may be used provided all other requirements of this Article are met.

(19) # VIII-850 TECHNIQUE

VIII-851 PROBE DATA ACQUISITION SPEED

The probe data acquisition speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities and be adjusted to provide a minimum digitization of 30 samples/in.

VIII-852 RECORDING

The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

VIII-853 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

VIII-860 CALIBRATION

VIII-861 EQUIPMENT CALIBRATION

VIII-861.1 Analog Equipment. The following shall be verified by annual calibration:

(a) the oscillator output frequency to the drive coil shall be within 5% of its indicated frequency

(b) the vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within 10% of the deflection of the input voltage

(c) the ratio of the output voltage from the tape recorder shall be within 5% of the input voltage for each channel of the tape recorder

(d) the chart speed from the strip chart recorder shall be within 5% of the indicated value

(e) amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency

VIII-861.2 Digital Equipment. Digital equipment shall be calibrated after repairs which may change the instrument's accuracy are made.

VIII-862 CALIBRATION REFERENCE STANDARDS

VIII-862.1 Calibration Reference Standard Requirements. Calibration reference standards shall conform to the following:

(a) Calibration reference standards shall be manufactured from tube(s) of the same material specification and nominal size as that to be examined.

(b) A comparison of the system null points observed in the calibration reference standard and the tubing to be examined shall be performed to validate that the resistivity of the calibration reference standard and the tubing being examined is comparable as determined by Level III.

(c) Artificial discontinuities in calibration reference standards shall be spaced axially so they can be individually evaluated and their eddy current responses can be differentiated from each other and from the ends of the tube. The as-built dimensions of the discontinuities shall become part of the permanent record of the calibration referenced specimen.

(d) Each calibration reference standard shall be permanently identified with a serial number.

VIII-862.2 Calibration Reference Standards for Differential and Absolute Bobbin Coils. Calibration reference standards shall contain the following artificial discontinuities as a minimum:

(a) A single hole drilled 100% through the tube wall, $^1/_{32}$ in. (0.8 mm) in diameter for $^3/_8$ in. (10 mm) and smaller O.D. tubing, $^3/_{64}$ in. (1.2 mm) in diameter for greater than $^3/_8$ in. (10 mm) to $^3/_4$ in. (19 mm) O.D. tubing, and $^1/_{16}$ in. (1.5 mm) for tubing larger than $^3/_4$ in. (19 mm) O.D.

(b) Four flat-bottom drill holes, $^3/_{16}$ in. (5 mm) in diameter, spaced 90-deg apart in a single plane around the tube circumference, 20% through the tube wall from the outer tube surface.

(c) One 360 deg circumferential groove, $^1/_8$ in. (3 mm) wide, 10% through the tube wall from the outer tube surface.

(d) One 360 deg circumferential groove, $^1/_{16}$ in. (1.5 mm) wide, 10% through the tube wall from the inner tube surface. Optional on smaller diameter tubing that may not facilitate tooling.

(e) The depth of the calibration discontinuities, at their center, shall be accurate to within 20% of the specified depth or 0.003 in. (0.076 mm), whichever is smaller. All other dimensions of the calibration discontinuities shall be accurate to within 0.010 in. (0.25 mm).

(f) Additional calibration discontinuities that simulate the anticipated or known conditions in the tubing or as specifically defined by the owner may be included on the same calibration standard with the above required discontinuities or on a separate standard.

(g) The additional calibration discontinuities described in (f) do not need to meet the tolerances in (e) as long as they simulate the anticipated conditions of the tubing to be examined and their actual as-built dimensions are used for the evaluation of the data.

(h) The additional calibration discontinuities described in (f) should

(1) allow for three calibration curve set points (e.g., 60%, 40%, 20% through wall)

(2) have an adequate axial dimension to encompass the field of the probe coils [e.g., $^5/_8$ in. (15 mm)] for large volume wall loss discontinuities, such as steam erosion or tube-to-tube wear

VIII-863 BASE FREQUENCY

The base frequency shall be between f_{90} and $2.1 \times f_{90}$ as defined by the following equations:

(a) Minimum Base Frequency:

$$f_{90} = 4.8\frac{\rho}{t^2\mu_r}$$

(b) Maximum Base Frequency:

$$2.1 \times f_{90} = 10\frac{\rho}{t^2\mu_r}$$

where

f_{90} = the frequency which generates a 90 deg phase separation between a shallow inside originated defect and a shallow outside originated defect
ρ = tube material resistivity (μΩ·cm)
t = tube wall thickness [in. or (mm/25)]
μ_r = relative magnetic permeability (μ_r = 1.0 for nonmagnetic materials)

VIII-864 SETUP AND ADJUSTMENT

VIII-864.1 Differential Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum Lissajous response of 50% screen height from the four 20% flat-bottom holes or as determined by the cognizant Level III or data analyst.

(b) The phase rotation shall be adjusted so the signal response due to the 10% inside originated groove is within 5 deg of the horizontal axis (max rate). The response due to the through-wall hole forms either up and to the left or down and to the right first as the probe is withdrawn from the calibration reference standard.

(c) Withdraw the probe through the calibration reference standard at the qualified examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

(d) The f_{90} frequency should be verified by a 90 deg phase separation between the inside and outside originated 10% deep grooves. See example in Figure VIII-864.1.

VIII-864.2 Absolute Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum Lissajous response of 25% screen height from the four 20% flat-bottom holes or as determined by the cognizant Level III or data analyst.

(b) The phase rotation control shall be adjusted so the signal response due to the 10% inside originated groove is within 5 deg (peak-to-peak) of the horizontal axis. The signal response due to the through-wall hole can be formed up and to the left or down and to the right as the probe is withdrawn from the calibration reference standard.

(c) Withdraw the probe through the calibration reference standard at the qualified examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

(d) The f_{90} frequency should be verified by a 90 deg phase separation between the inside and outside originated 10% deep grooves. See example in Figure VIII-864.2.

VIII-864.3 Digital System Off-Line Calibration. The eddy current examination data is digitized and recorded during scanning for off-line analysis and interpretation. The system setup of phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

VIII-864.4 System Calibration Verification.

(a) Calibration shall include the complete eddy current examination system. Changes of any probe, extension cables, eddy current instrument, recording instruments,

Figure VIII-864.1
Differential Technique Response From Calibration Reference

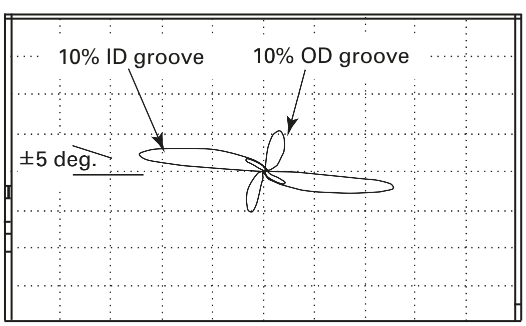
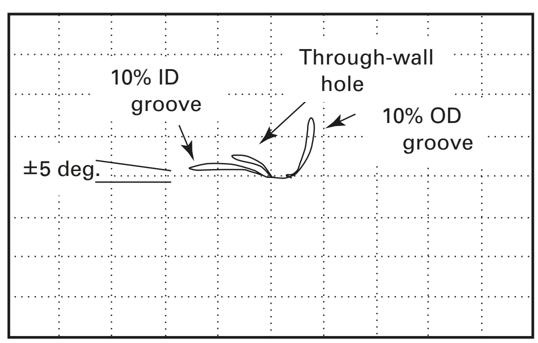


Figure VIII-864.2
Absolute Technique From Calibration Reference Standard



or any other parts (essential variables) of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media and every 4 hr.

(c) Should the system be found to be out of calibration (as defined in VIII-864.1 and VIII-864.2), the equipment shall be recalibrated. The recalibration shall be noted on the recording media. The cognizant Level III or data analyst shall determine which tubes, if any, shall be reexamined.

VIII-870 EXAMINATION

The maximum probe travel speed used for examination shall not exceed that used for calibration. Data shall be recorded as the probe traverses the tube.

(19) VIII-880 EVALUATION

VIII-881 DATA EVALUATION

Data shall be evaluated in accordance with the requirements of this Appendix.

VIII-882 MEANS OF DETERMINING INDICATION DEPTH

For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have been qualified. This shall be accomplished by using curves, tables, or equations and aided by software.

VIII-883 FREQUENCIES USED FOR DATA EVALUATION

All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

(19) VIII-890 DOCUMENTATION

VIII-891 REPORTING

VIII-891.1 Criteria. Indications reported in accordance with the requirements of this Appendix shall be described in terms of the following information, as a minimum:

(a) location along the length of the tube and with respect to the support members, when the indication identification is relevant to a specific location (i.e., fretting @ baffle 2)

(b) depth of the indication through the tube wall

(c) frequency or frequency mix from which the indication was evaluated

VIII-891.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of tube wall loss. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

VIII-891.3 Nonquantifiable Indications. A nonquantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

VIII-892 SUPPORT MEMBERS

VIII-892.1 Location of Support. The location of support members used as reference points for the eddy current examination shall be verified by fabrication drawings or the use of a measurement technique.

VIII-893 RECORDS

VIII-893.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

(a) procedure identification and revision
(b) plant site, unit, and Owner
(c) heat exchanger identification
(d) data storage unit number
(e) date of examination
(f) serial number of the calibration standard
(g) operator's identification and certification level
(h) examination frequency or frequencies
(i) mode of operation including instrument sample rate, drive voltage, and gain settings
(j) lengths of probe and probe extension cables
(k) size and type of probes
(l) probe manufacturer's name and manufacturer's part number or probe description and serial number
(m) eddy current instrument model and serial number
(n) probe scanning mode and direction during data acquisition
(o) application side — inlet or outlet
(p) slip ring serial number, as applicable
(q) tube material, size, and wall thickness

VIII-893.2 Tube Identification.

(a) Each tube examined shall be identified on the applicable unit of data storage and should be consistent with the manufacturer's as-built drawings, Owner's numbering scheme, and/or previous inspection.

(b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

VIII-893.3 Reporting.

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing

Code Section. The procedures and equipment used shall be sufficiently identified to permit the comparison of existing results to those of previous and subsequent examinations. This shall include initial calibration data for each eddy current examination system or part thereof.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

VIII-893.4 Record Retention. Records shall be maintained in accordance with requirements of the referencing Code Section.

(19)

MANDATORY APPENDIX IX
EDDY CURRENT ARRAY EXAMINATION OF FERROMAGNETIC AND NONFERROMAGNETIC MATERIALS FOR THE DETECTION OF SURFACE-BREAKING FLAWS

IX-810 SCOPE

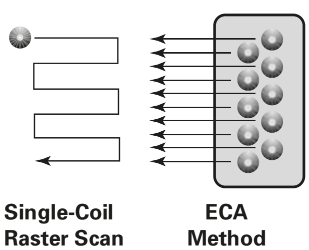
This Appendix provides the requirements for the detection and length sizing of surface-breaking flaws on ferromagnetic and nonferromagnetic materials using the eddy current array (ECA) technique.

IX-820 GENERAL REQUIREMENTS

IX-821 ECA TECHNIQUE

The ECA technique may be applied to detect linear and nonlinear surface-breaking flaws. Length sizing of flaws may also be accomplished when an encoder is used. ECA may be used on ferromagnetic and nonferromagnetic materials. ECA provides the ability to electronically monitor the output of multiple eddy-current sensing coils placed side by side or in other orientations within the same probe assembly. The ECA technique effectively replaces raster scanning with a single-pass scan, provided the probe size is adequate to cover the area of interest (see Figure IX-821-1). When a surface flaw is encountered by the magnetic field of an individual coil, eddy currents generated in the material change their flow and provide a secondary magnetic field in opposition to the coil's primary magnetic field. Modifications to the coil's primary magnetic field are processed and presented on the equipment's strip chart, phase-amplitude diagram, and two-dimensional and/or three-dimensional C-scan displays.

Figure IX-821-1
ECA Technique Compared to Raster Scan



IX-822 WRITTEN PROCEDURE REQUIREMENTS

The ECA examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table IX-822-1. The written procedure shall establish a single value, or a range of values, for each requirement.

IX-823 PROCEDURE QUALIFICATION

When a written procedure qualification is specified by the referencing Code Section, a change of a requirement in Table IX-822-1 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

IX-824 PERSONNEL QUALIFICATION

The user shall be responsible for assigning qualified personnel to perform the ECA examinations in accordance with the requirements of this Appendix, the referencing Code Section, and their employer's written practice. The minimum qualification level of personnel performing ECA examinations shall be Eddy Current (ET) Level II with a minimum of 20 hr supplemental ECA training. Supplemental training on the use of the ECA method shall cover, at a minimum, the following topics:

(a) training on the specific ECA hardware and software used

(b) ECA advantages and limitations

(c) ECA probe types, construction, and operation

(d) channel standardization

(e) C-scan interpretation

(f) phase-amplitude data analysis interpretation

(g) encoded scans

Table IX-822-1
Written Procedure Requirements for an ECA Examination

Requirement	Essential Variable	Nonessential Variable
Instrument (manufacturer, model)	X	...
Probe (manufacturer, model)	X	...
ECA probe topology	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Scanning mode (e.g., manual, mechanized, or remote-controlled)	X	...
Scan plan, coverage, overlap, and scanning direction	X	...
Identity of calibration reference standard(s)	X	...
Minimum sample density along scanning axis [samples/inch (samples/millimeter)]	X	...
Surface condition	X	...
Maximum scanning speed during data acquisition	X	...
Personnel qualification	X	...
Data recording	...	X
Data analysis parameters	...	X
Examination specimen numbering	...	X

IX-825 PROCEDURE DEMONSTRATION

The examination procedure shall be demonstrated to the satisfaction of the Inspector and responsible Level III in accordance with requirements of the referencing Code Section.

IX-830 EQUIPMENT

IX-831 DIGITAL DATA ACQUISITION EQUIPMENT

ECA equipment shall manage the ECA probe signals based on a channel multiplexing or a parallel channel system. ECA instrumentation with a minimum frequency range of 1 kHz to 4 MHz and associated software shall be used. The ECA instrument and software shall

(a) allow standardizing the ECA probe signal response by conducting individual adjustments (e.g., scaling) to the data response of each coil channel in order to provide a uniform response and sensitivity among the array channels (i.e., channel standardization).

(b) display data as a two-dimensional C-scan allowing for image-based analysis. Data shall also be displayed in the traditional phase-amplitude diagram and strip chart views.

(c) allow adjustment of encoder settings and display resolution (inch/sample [millimeter/sample]).

(d) allow recording of the ECA data in a format for evaluation and archival storage.

IX-832 PROBES

ECA probes shall

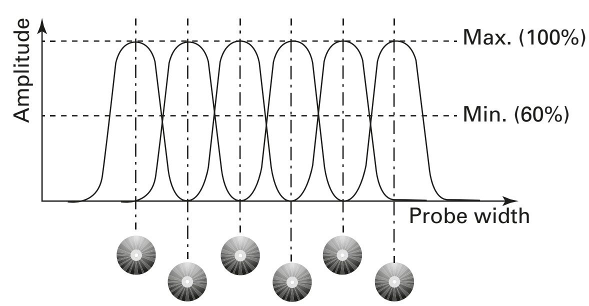
(a) provide coverage that extends 0.125 in. (3.2 mm) beyond the area of interest unless multiple overlapping scans are used.

(b) exhibit a uniform sensitivity across the array sensor. Overlapping individual sensing elements may be required to achieve a level of uniform sensitivity (e.g., multiple staggered rows of single sensing elements is typical). For the purpose of detection only, multiple scans of the same reference standard flaw shall maintain an amplitude response of at least 60% of the maximum amplitude detected. See Figure IX-832-1.

(c) allow detection of volumetric and linear surface-breaking flaws in all orientations.

(d) match the geometry of the area of interest to minimize the distance between the surface examined and the individual sensing elements (i.e., lift-off).

Figure IX-832-1
Array Coil Sensitivity Variance



GENERAL NOTE: Multiple scans of the same flaw shall consistently provide at least 60% of the maximum detected amplitude.

IX-833 REFERENCE STANDARD (SEE FIGURE IX-833-1)

A reference standard shall be constructed of the same material grade as to be examined. The surface roughness of the reference standard shall be representative of the surface roughness of the component surface to be examined. The reference standard shall have 1.5 in. (38 mm) of a flaw-free region at the beginning and end of the longitudinal scanning direction. Ferromagnetic and nonferromagnetic reference standards shall have a minimum of one flat-bottom hole and three surface notches. The surface notches shall include oblique (i.e., 45 deg), transverse, and longitudinal orientations. The distance between flaws in the same longitudinal direction shall be a minimum of 0.5 in. (13 mm). The flat-bottom hole shall have a maximum diameter and depth of 0.062 in. (1.57 mm) and 0.040 in. (1.0 mm), respectively. Each notch length, width, and depth shall be a maximum of 0.062 in. (1.57 mm), 0.010 in. (0.25 mm), and 0.040 in. (1.0 mm), respectively. In addition, reference standards for ferromagnetic and nonferromagnetic materials shall have a long transverse notch of constant depth for use with channel standardization. The length of the long transverse notch shall be at least 1.0 in. (25 mm) longer than the coverage of the ECA probe coils. The width and depth of the long notch shall be a maximum of 0.010 in. (0.25 mm) and 0.040 in. (1.0 mm), respectively. When the examination region of interest is a curved surface requiring a rigid probe with a matching contoured surface, a reference specimen representing that particular geometry with the above referenced flaws shall be used. Machining during the manufacture of the reference standard shall avoid excessive cold-working, overheating, and stress to prevent magnetic permeability variations.

IX-840 APPLICATION REQUIREMENTS

IX-841 SCANNING SPEED

The scanning speed shall not exceed that which provides detection of the reference standard flaws. A data-amplitude-based signal-to-noise ratio (SNR) for all flaws shall be maintained at a value greater than 3. The minimum sample density along the scanning axis shall be 50.0 samples/in. (2.0 samples/mm).

IX-842 COATED SURFACES

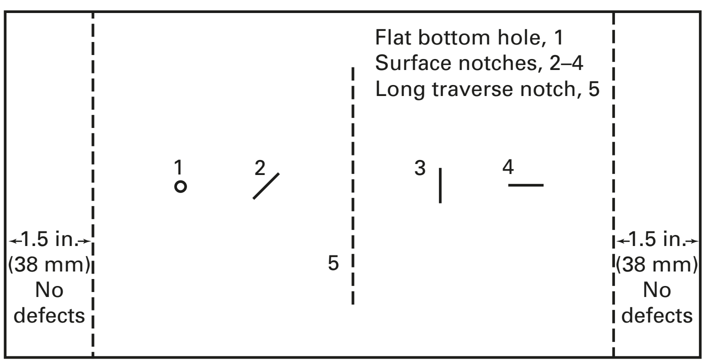
(a) When examining a coated material, the coating thickness on the reference standard shall be the maximum allowed on the examination surface by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification.

(b) Using the maximum scanning speed specified by the procedure, the procedure shall be demonstrated to consistently detect the reference standard flaws through the maximum coating thickness regardless of flaw orientation. A data-amplitude-based SNR for all flaws shall be maintained at a value greater than 3.

IX-843 MAGNETIC PERMEABILITY VARIANCE

In the event that the magnetic permeability along the scanning axis changes to the extent that the ECA data signals on the phase-amplitude diagram become saturated, the NDE technician shall perform a system calibration verification using the reference standard, rebalance the instrument with the probe positioned in the affected area, and rescan the region.

Figure IX-833-1
Example Reference Standard



IX-844 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems (e.g., alarm boxes) are used, each system shall be qualified in accordance with a written procedure.

IX-850 TECHNIQUE

IX-851 FREQUENCY, PROBE DRIVE, AND GAIN SELECTION

A single-frequency or multifrequency technique may be used. The frequency shall be selected to maximize the phase spread between the lift-off signal and reference flaws. Probe drive and gain shall be adjusted until the response of the reference flaws has a data-amplitude-based SNR greater than 3.

IX-852 CHANNEL STANDARDIZATION

If the topology selected for an examination features different channel types (e.g., longitudinal and transverse sensitivity), channel standardization shall be performed for each channel type. The flaw response from each array channel shall be reviewed via the traditional phase-amplitude diagram to ensure that the channel standardization was completed successfully. The channel standardization process shall be performed on a reference standard with a machined notch of known length, width, and depth. Other reference points such as known lift-off or a metal-to-air transition may be used if equivalent performance to a machined notch can be demonstrated.

IX-853 COLOR PALETTE ADJUSTMENT

The color palette scale shall be adjusted until the reference flaws can be clearly distinguished when compared to lift-off, geometry change, and non-flaw-related signals.

IX-860 CALIBRATION

IX-861 EQUIPMENT CALIBRATION

ECA instrumentation shall be calibrated annually, when the equipment is subjected to damage, and/or after any major repair. A label showing the latest date of calibration and calibration due date shall be attached to the ECA instrument.

IX-862 SYSTEM CALIBRATION AND VERIFICATION

(a) System calibration of the examination equipment shall be performed with the use of a reference standard as specified in the written procedure. This calibration shall include the complete eddy current examination system and shall be performed prior to the start of the examination. A verification shall be performed at the conclusion of the examination or series of examinations.

(b) Calibration verification using the reference standard shall be performed when either of the following occurs:

(1) a change in material properties that causes signal saturation

(2) examination of a new component

IX-870 EXAMINATION

IX-871 SURFACE CONDITION

Cleaning of the material surface shall be conducted to remove loose ferromagnetic, conductive, and nonconductive debris.

IX-872 SCANNING METHOD (SEE FIGURE IX-872-1)

Pressure applied to the ECA probe shall be sufficient to maintain contact with the part under examination. When using a conformable array probe, consistent pressure shall be applied across all coils. The area of interest shall be examined with overlapping scans. Overlap along the scanning axis (i.e., scanning direction) shall include the end of the previous scan by at least one probe width. Overlap along the index axis shall include 0.250 in. (6.4 mm) of the previous scan. Note that the probe length overlap value [0.250 in. (6.4 mm)] is based on the coil sensitivity length within the probe body.

IX-873 SECONDARY SCANNING

When an encoder is not used, flaw locations may be confirmed by a supplemental manual single-channel eddy current (EC) technique, provided it has been qualified by a performance demonstration.

IX-880 EVALUATION

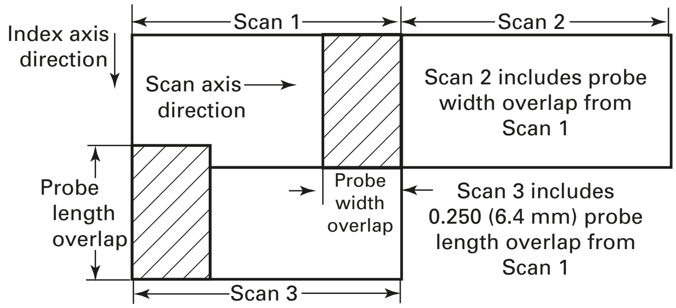
IX-881 RELEVANT VS. NONRELEVANT INDICATIONS

Nonrelevant indications may be produced by inconsistent probe contact with the surface, probe motion caused by geometric features, or changes in the material properties of the surface being examined. Indications that exhibit a phase response equivalent to a flaw response as demonstrated on the reference standard and that cannot be differentiated as a nonrelevant indication shall be evaluated and reported as a flaw.

IX-882 LENGTH SIZING

An encoder shall be used to accurately measure flaw length. The encoder resolution value shall be set to a maximum of 0.015 in./sample (0.38 mm/sample).

Figure IX-872-1
Scanning Overlap



IX-890 DOCUMENTATION

IX-891 EXAMINATION REPORT

A report of the examination shall be generated. The report shall include, at a minimum, the following information:

(a) owner, location, type, serial number, and identification of test specimen examined

(b) material examined

(c) test specimen numbering system

(d) dimensions of surface area to be examined

(e) personnel performing the examination

(f) date of examination

(g) ECA equipment manufacturer, model, and serial number

(h) ECA probe manufacturer, model, and serial number

(i) instrument hardware settings (frequency, probe drive, gain, and sample rate)

(j) serial number(s), material, and drawing(s) of reference standard(s)

(k) procedure used, identification, and revision

(l) acceptance criteria used

(m) identification of regions of test specimens where limited sensitivity or other areas of reduced sensitivity occur

(n) results of the examination and related sketches or maps of the examined area

(o) complementary tests used to further investigate or confirm test results

(p) extension cable, manufacturer, type, and length

(q) qualification level of eddy current personnel

(r) coating-thickness gauge when required

IX-892 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX X EDDY CURRENT ARRAY EXAMINATION OF FERROMAGNETIC AND NONFERROMAGNETIC WELDS FOR THE DETECTION OF SURFACE-BREAKING FLAWS (19)

X-810 SCOPE

This Appendix provides the requirements for the detection and length sizing of surface-breaking flaws on ferromagnetic and nonferromagnetic welds using the eddy current array (ECA) technique.

X-820 GENERAL REQUIREMENTS

X-821 ECA TECHNIQUE

The ECA technique may be applied to detect linear and nonlinear surface-breaking flaws. Length sizing of flaws may also be accomplished when an encoder is used. ECA may be used on ferromagnetic and nonferromagnetic welds. ECA provides the ability to electronically monitor the output of multiple eddy-current sensing coils placed side by side or in other orientations within the same probe assembly. The ECA technique effectively replaces raster scanning with a single-pass scan, provided the probe size is adequate to cover the area of interest (see Mandatory Appendix IX, Figure IX-821-1). When a surface flaw is encountered by the magnetic field of an individual coil, eddy currents generated in the material change their flow and provide a secondary magnetic field in opposition to the coil's primary magnetic field. Modifications to the coil's primary magnetic field are processed and presented on the equipment's strip chart, phase-amplitude diagram, and two-dimensional and/or three-dimensional C-scan displays.

X-822 WRITTEN PROCEDURE REQUIREMENTS

The ECA examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table X-822-1. The written procedure shall establish a single value, or a range of values, for each requirement.

X-823 PROCEDURE QUALIFICATION

When a written procedure qualification is specified by the referencing Code Section, a change of a requirement in Table X-822-1 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

X-824 PERSONNEL QUALIFICATION

The user shall be responsible for assigning qualified personnel to perform the ECA examinations in accordance with the requirements of this Appendix, the referencing Code Section, and their employer's written practice. The minimum qualification level of personnel performing ECA examinations shall be Eddy Current (ET) Level II with a minimum of 20 hr supplemental ECA training. Supplemental training on the use of the ECA method shall, at a minimum, cover the following topics:

(a) training on the specific ECA hardware and software used

(b) ECA advantages and limitations

(c) ECA probe types, construction, and operation

(d) channel standardization

(e) C-scan interpretation

(f) phase-amplitude data analysis interpretation

(g) encoded scans

X-825 PROCEDURE DEMONSTRATION

The procedure shall be demonstrated to the satisfaction of the Inspector and responsible Level III in accordance with the requirements of the referencing Code Section.

X-830 EQUIPMENT

X-831 DIGITAL DATA ACQUISITION EQUIPMENT

ECA equipment shall manage the ECA probe signals based on a channel multiplexing or a parallel channel system. ECA instrumentation with a minimum frequency range of 1 kHz to 4 MHz and associated software shall be used. The ECA instrument and software shall

(a) allow standardizing the ECA probe signal response by conducting individual adjustments (e.g., scaling) to the data response of each coil channel in order to provide a uniform response and sensitivity among the array channels (i.e., channel standardization).

Table X-822-1
Written Procedure Requirements for an ECA Examination

Requirement	Essential Variable	Nonessential Variable
Instrument (manufacturer, model)	X	...
Probe (manufacturer, model)	X	...
ECA probe topology	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Scanning mode (e.g., manual, mechanized, or remote controlled)	X	...
Scan plan, coverage, overlap, and scanning direction	X	...
Identity of calibration reference standard(s)	X	...
Minimum sample density along scanning axis [samples/inch (samples/millimeter)]	X	...
Surface condition	X	...
Maximum scanning speed during data acquisition	X	...
Personnel qualification	X	...
Data recording	...	X
Data analysis parameters	...	X
Examination specimen numbering	...	X

(b) display data as a two-dimensional C-scan allowing for image-based analysis. Data shall also be displayed in the traditional phase-amplitude diagram and strip chart views.

(c) allow adjustment of encoder settings and display resolution [inch/sample (millimeter/sample)].

(d) allow recording of the ECA data in a format for evaluation and archival storage.

X-832 PROBES

ECA probes shall

(a) provide coverage that extends 0.125 in. (3.2 mm) beyond the area of interest inclusive of the heat-affected zone (HAZ), unless multiple overlapping scans are used.

(b) exhibit a uniform sensitivity across the array sensor. Overlapping individual sensing elements may be required to achieve a level of uniform sensitivity (e.g., multiple staggered rows of single sensing elements is typical). For the purpose of detection only, multiple scans of the same reference standard flaw shall maintain an amplitude response of at least 60% of the maximum amplitude detected. See Mandatory Appendix IX, Figure IX-832-1.

(c) allow detection of volumetric and linear surface-breaking flaws in all orientations.

(d) match the geometry of the area of interest to minimize the distance between the surface examined and the individual sensing elements (i.e., lift-off).

X-833 REFERENCE STANDARD (SEE FIGURE X-833-1)

X-833.1 General Requirements. A reference standard shall be constructed of the same material grade as to be examined. The surface roughness of the reference standard shall be representative of the surface roughness of the component surface to be examined. The reference standard shall have 1.5 in. (38 mm) of a flaw-free region at the beginning and end of the longitudinal scanning direction. Ferromagnetic and nonferromagnetic reference standards shall have a minimum of four flat-bottom holes and 12 surface notches. The surface notches shall have oblique (45 deg), transverse, and longitudinal orientations. The distance between flaws in the same longitudinal direction shall be a minimum of 0.5 in. (13 mm). Each flaw type shall be located in the HAZ, the crown of the weld, the fusion line of the weld, and the base material. In addition, reference standards for ferromagnetic and nonferromagnetic weld applications shall have a long transverse notch of constant depth for use with channel standardization. The length of the long transverse notch shall be at least 1.0 in. (25 mm) longer than the coverage of the ECA probe coils. The width and depth of the long notch shall be a maximum of 0.010 in. (0.25 mm) and 0.040 in. (1.0 mm), respectively. When the examination region of interest is a curved surface requiring a rigid probe with a matching contoured surface, a reference specimen representing that particular geometry with the above referenced flaws shall be used. Machining during the manufacture of the reference standard shall avoid excessive cold-working, overheating, and stress to prevent magnetic permeability variations.

X-833.2 Flush Welds. The flat-bottom holes and notches for flush weld reference standards shall have the following maximum dimensions:

(a) Flat-Bottom Holes

(1) diameter of 0.062 in. (1.57 mm)

(2) depth of 0.040 in. (1.0 mm)

(b) Notches

(1) length of 0.062 in. (1.57 mm)

(2) width of 0.010 in. (0.25 mm)

(3) depth of 0.040 in. (1.0 mm)

X-833.3 Nonflush Welds. The flat-bottom holes and notches for nonflush weld reference standards shall have the following maximum dimensions:

(a) Flat-Bottom Holes

(1) diameter of 0.125 in. (3.2 mm)

(2) depth of 0.040 in. (1.0 mm)

(b) Notches

(1) length of 0.188 in. (4.8 mm)

(2) width of 0.010 in. (0.25 mm)

(3) depth of 0.040 in. (1.0 mm)

X-840 APPLICATION REQUIREMENTS

X-841 SCANNING SPEED

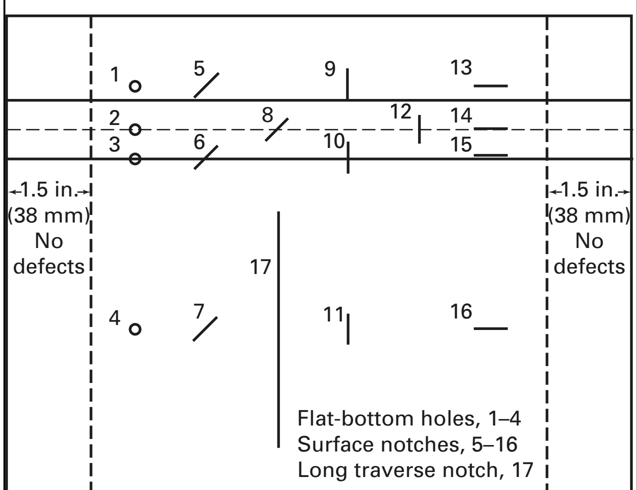
The scanning speed shall not exceed that which provides detection of the reference standard flaws. A data-amplitude-based signal-to-noise ratio (SNR) for all flaws shall be maintained at a value greater than 3. The minimum sample density along the scanning axis shall be 50.0 samples/in. (2.0 samples/mm).

X-842 COATED SURFACES

(a) When examining a coated material, the coating thickness on the reference standard shall be the maximum allowed on the examination surface by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification.

(b) Using the maximum scanning speed specified by the procedure, the procedure shall be demonstrated to consistently detect the reference standard flaws through the maximum coating thickness regardless of flaw orientation. A data-amplitude-based SNR for all flaws shall be maintained at a value greater than 3.

Figure X-833-1
Example Reference Standard



X-843 MAGNETIC PERMEABILITY VARIANCE

In the event that the magnetic permeability along the scanning axis changes to the extent that the ECA data signals on the phase-amplitude diagram become saturated, the NDE technician shall perform a system calibration verification using the reference standard, rebalance the instrument with the probe positioned in the affected area, and rescan the region.

X-844 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems (e.g., alarm boxes) are used, each system shall be qualified in accordance with a written procedure.

X-850 TECHNIQUE

X-851 FREQUENCY, PROBE DRIVE, AND GAIN SELECTION

A single-frequency or multifrequency technique may be used. The frequency shall be selected to maximize the phase spread between the lift-off signal and reference flaws. Probe drive and gain shall be adjusted until the response of the reference flaws has a data-amplitude-based SNR greater than 3.

X-852 CHANNEL STANDARDIZATION

If the topology selected for an examination features different channel types (e.g., longitudinal and transverse sensitivity), channel standardization shall be performed for each channel type. The flaw response from each array channel shall be reviewed via the traditional phase-amplitude diagram to ensure that the channel standardization was completed successfully. The channel standardization process shall be performed on a reference standard with a machined notch of known length, width, and depth. Other reference points such as known lift-off or a metal-to-air transition may be used if equivalent performance to a machined notch can be demonstrated.

X-853 COLOR PALETTE ADJUSTMENT

The color palette scale shall be adjusted until the reference flaws can be clearly distinguished when compared to lift-off, geometry change, and non-flaw-related signals.

X-860 CALIBRATION

X-861 EQUIPMENT CALIBRATION

ECA instrumentation shall be calibrated annually, when the equipment is subjected to damage, and/or after any major repair. A label showing the latest date of calibration and calibration due date shall be attached to the ECA instrument.

X-862 CALIBRATION AND VERIFICATION

(a) System calibration of the examination equipment shall be performed with the use of a reference standard as specified in the written procedure. This calibration shall include the complete eddy current examination system and shall be performed prior to the start of the examination. A verification shall be performed at the conclusion of the examination or series of examinations.

(b) Calibration verification using the reference standard shall be performed when either of the following occurs:

(1) a change in material properties that causes signal saturation

(2) examination of a new component

X-870 EXAMINATION

X-871 SURFACE CONDITION

Cleaning of the weld surface shall be conducted to remove loose ferromagnetic, conductive, and nonconductive debris.

X-872 SCANNING METHOD (SEE MANDATORY APPENDIX IX, FIGURE IX-872-1)

Pressure applied to the ECA probe shall be sufficient to maintain contact with the part under examination. When using a conformable array probe, consistent pressure shall be applied across all coils. The area of interest shall be examined with overlapping scans. Overlap along the scanning axis (i.e., scanning direction) shall include the end of the previous scan by at least one probe width. Overlap along the index axis shall include 0.250 in. (6.4 mm) of the previous scan. Note that the probe length overlap value [0.250 in. (6.4 mm)] is based on the coil sensitivity length within the probe body.

X-873 SECONDARY SCANNING

When an encoder is not used, flaw locations may be confirmed by a supplemental manual single-channel eddy current (EC) technique, provided it has been qualified by a performance demonstration.

X-880 EVALUATION

X-881 RELEVANT VS. NONRELEVANT INDICATIONS

Nonrelevant indications may be produced by inconsistent probe contact with the surface, probe motion caused by geometric features, or changes in the material properties of the surface being examined. Indications that exhibit a phase response equivalent to a flaw response as demonstrated on the reference standard and that cannot be differentiated as a nonrelevant indication shall be evaluated and reported as a flaw.

X-882 LENGTH SIZING

An encoder shall be used to accurately measure flaw length. The encoder resolution value shall be set to a maximum of 0.015 in./sample (0.38 mm/sample).

X-890 DOCUMENTATION

X-891 EXAMINATION REPORT

A report of the examination shall be generated. The report shall include, at a minimum, the following information:

(a) owner, location, type, serial number, and identification of test specimen examined

(b) material examined

(c) test specimen numbering system

(d) dimensions of surface area to be examined

(e) personnel performing the examination

(f) date of examination

(g) ECA equipment manufacturer, model, and serial number

(h) ECA probe manufacturer, model, and serial number

(i) instrument hardware settings (frequency, probe drive, gain, and sample rate)

(j) serial number(s), material, and drawing(s) of reference standard(s)

(k) procedure used, identification, and revision

(l) acceptance criteria used

(m) identification of regions of test specimens where limited sensitivity or other areas of reduced sensitivity occur

(n) results of the examination and related sketches or maps of the examined area

(o) complementary tests used to further investigate or confirm test results

(p) extension cable, manufacturer, type, and length

(q) qualification level of eddy current personnel

(r) coating thickness gauge when required

X-892 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

ARTICLE 9
VISUAL EXAMINATION

T-910 SCOPE

(a) This Article contains methods and requirements for visual examination applicable when specified by a referencing Code Section. Specific visual examination procedures required for every type of examination are not included in this Article, because there are many applications where visual examinations are required. Some examples of these applications include nondestructive examinations, leak testing, in-service examinations and fabrication procedures.

(b) The requirements of Article 1, General Requirements, apply when visual examination, in accordance with Article 9, is required by a referencing Code Section.

(c) Definitions of terms for visual examination appear in Article 1, Mandatory Appendix I, I-121.6, VT — Visual Examination.

T-920 GENERAL

T-921 WRITTEN PROCEDURE REQUIREMENTS

T-921.1 Requirements. Visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-921. The written procedure shall establish a single value, or range of values, for each requirement.

T-921.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-921 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-921.3 Demonstration. The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $^{1}/_{32}$ in. (0.8 mm) or less in width, an artificial imperfection or a simulated condition, located on the surface or a similar surface to that to be examined, may be considered as a method for procedure demonstration. The condition or artificial imperfection should be in the least discernable location on the area surface to be examined to validate the procedure.

T-922 PERSONNEL REQUIREMENTS

The user of this Article shall be responsible for assigning qualified personnel to perform visual examinations to the requirements of this Article. At the option of the organization, he may maintain one certification for each product, or several separate signed records based on the area or type of work, or both combined. Where impractical to use specialized visual examination personnel, knowledgeable and trained personnel, having limited qualifications, may be used to perform specific examinations, and to sign the report forms. Personnel performing examinations shall be qualified in accordance with requirements of the referencing Code Section.

T-923 PHYSICAL REQUIREMENTS

Personnel shall have an annual vision test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

Table T-921
Requirements of a Visual Examination Procedure (19)

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Change in technique used	...	...
Direct to or from translucent	X	...
Direct to remote	X	...
Remote visual aids	X	...
Personnel performance requirements, when required	...	X
Lighting intensity (decrease only)	X	...
Configurations to be examined and base material product forms (pipe, plate, forgings, etc.)	...	X
Lighting equipment	...	X
Methods or tools used for surface preparation	...	X
Equipment or devices used for a direct technique	...	X
Sequence of examination	...	X
Personnel qualifications	...	X

T-930 EQUIPMENT

Equipment used for visual examination techniques, for example, direct, remote, or translucent, shall have the capabilities as specified in the procedure. Capabilities include, but are not limited to viewing, magnifying, identifying, measuring, and/or recording observations in accordance with requirements of the referencing Code Section.

T-950 TECHNIQUE

T-951 APPLICATIONS

Visual examination is generally used to determine such things as the surface condition of the part, alignment of mating surfaces, shape, or evidence of leaking. In addition, visual examination is used to determine a composite material's (translucent laminate) subsurface conditions.

(19) T-952 DIRECT VISUAL EXAMINATION

Direct visual examination may usually be made when access is sufficient to place the eye within 24 in. (600 mm) of the surface to be examined and at an angle not less than 30 deg to the surface to be examined. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens may be used to assist examinations. Illumination (natural or supplemental white light) of the examination surface is required for the specific part, component, vessel, or section thereof being examined. The minimum light intensity shall be 100 fc (1 076 lx). The light intensity, natural or supplemental white light source, shall be measured with a white light meter prior to the examination or a verified light source shall be used. Verification of light sources is required to be demonstrated only one time, documented, and maintained on file.

(19) T-953 REMOTE VISUAL EXAMINATION

In some cases, remote visual examination may have to be substituted for direct examination. Remote visual examination may use visual aids such as mirrors, telescopes, borescopes, fiber optics, cameras, or other suitable instruments. Such systems shall have a resolution capability and light intensity at least equivalent to that obtainable by direct visual observation.

T-954 TRANSLUCENT VISUAL EXAMINATION

Translucent visual examination is a supplement of direct visual examination. The method of translucent visual examination uses the aid of artificial lighting, which can be contained in an illuminator that produces directional lighting. The illuminator shall provide light of an intensity that will illuminate and diffuse the light evenly through the area or region under examination. The ambient lighting must be so arranged that there are no surface glares or reflections from the surface under examination and shall be less than the light applied through the area or region under examination. The artificial light source shall have sufficient intensity to permit "candling" any translucent laminate thickness variations.

T-955 LIGHT METER CALIBRATION (19)

Light meters shall be calibrated at least once a year or whenever they have been repaired. If meters have not been in use for 1 yr or more, they shall be calibrated before they are used.

T-980 EVALUATION (19)

(a) All examinations shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) An examination checklist shall be used to plan visual examination and to verify that the required visual observations were performed. This checklist establishes minimum examination requirements and does not indicate the maximum examination which the Manufacturer may perform in process.

T-990 DOCUMENTATION

T-991 REPORT OF EXAMINATION (19)

(a) A written report of the examination shall contain the following information:

(1) the date of the examination

(2) procedure identification and revision used

(3) technique used

(4) results of the examination

(5) examination personnel identity, and, when required by the referencing Code Section, qualification level

(6) identification of the part or component examined

(b) Even though dimensions, etc., were recorded in the process of visual examination to aid in the evaluation, there need not be documentation of each viewing or each dimensional check. Documentation shall include all observation and dimensional checks specified by the referencing Code Section.

T-993 RECORD MAINTENANCE

Records shall be maintained as required by the referencing Code Section.

ARTICLE 10
LEAK TESTING

T-1010 SCOPE

This Article describes methods and requirements for the performance of leak testing.

(a) When a leak testing method or technique of Article 10 is specified by a referencing Code Section, the leak test method or technique shall be used together with Article 1, General Requirements.

(b) Definition of terms used in this Article are in Article 1, Mandatory Appendix I, I-121.7, LT — Leak Testing.

(c) The test methods or techniques of these methods can be used for the location of leaks or the measurement of leakage rates.

The specific test method(s) or technique(s) and Glossary of Terms of the methods in this Article are described in Mandatory Appendices I through X of Article 10 as follows:

Mandatory Appendix I — Bubble Test — Direct Pressure Technique

Mandatory Appendix II — Bubble Test — Vacuum Box Technique

Mandatory Appendix III — Halogen Diode Detector Probe Test

Mandatory Appendix IV — Helium Mass Spectrometer Test — Detector Probe Technique

Mandatory Appendix V — Helium Mass Spectrometer Test — Tracer Probe Technique

Mandatory Appendix VI — Pressure Change Test

Mandatory Appendix VIII — Thermal Conductivity Detector Probe Test

Mandatory Appendix IX — Helium Mass Spectrometer Test — Hood Technique

Mandatory Appendix X — Ultrasonic Leak Detector Test

Mandatory Appendix XI — Helium Mass Spectrometer — Helium-Filled-Container Leakage Rate Test

Nonmandatory Appendix A — Supplementary Leak Testing Equation Symbols

T-1020 GENERAL

T-1021 WRITTEN PROCEDURE REQUIREMENTS

T-1021.1 Requirements. Leak testing shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in the applicable Appendices, paras. I-1021 through X-1021 and Tables I-1021 through X-1021. The written procedure shall establish a single value, or range of values, for each requirement.

T-1021.2 Modification of Requirements. Article 10 contains test techniques; therefore, there are requirements that cannot be modified by the organization through the demonstration process per T-150. Only those requirements listed in Tables I-1021 through X-1021 may be so modified by demonstration.

T-1021.3 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in the applicable Appendix Tables I-1021 through X-1021 identified as an *essential* variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a *nonessential* variable does not require requalification of the written procedure. All changes of essential and nonessential elements from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1022 REFERENCING CODE

For the leak testing method(s) or technique(s) specified by the referencing Code, the referencing Code Section shall then be consulted for the following:

(a) personnel qualification/certification

(b) technique(s)/calibration standards

(c) extent of examination

(d) acceptable test sensitivity or leakage rate

(e) report requirements

(f) retention of records

T-1030 EQUIPMENT

T-1031 GAGES

(a) Gage Range. When dial indicating and recording pressure gage(s) are used in leak testing, they should preferably have the dial(s) graduated over a range of approximately double the intended maximum pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more

than four times that pressure. These range limits do not apply to dial indicating and recording vacuum gages. Range requirements for other types of gages given in an applicable Mandatory Appendix shall be as required by that Appendix.

(b) Gage Location. When components are to be pressure/vacuum leak tested, the dial indicating gage(s) shall be connected to the component or to the component from a remote location, with the gage(s) readily visible to the operator controlling the pressure/vacuum throughout the duration of pressurizing, evacuating, testing, and depressurizing or venting of the component. For large vessels or systems where one or more gages are specified or required, a recording type gage is recommended, and it may be substituted for one of the two or more indicating type gages.

(c) When other types of gage(s) are required by an applicable Mandatory Appendix, they may be used in conjunction with or in place of dial indicating or recording type gages.

T-1040 MISCELLANEOUS REQUIREMENTS

T-1041 CLEANLINESS

The surface areas to be tested shall be free of oil, grease, paint, or other contaminants that might mask a leak. If liquids are used to clean the component or if a hydrostatic or hydropneumatic test is performed before leak testing, the component shall be dry before leak testing.

T-1042 OPENINGS

All openings shall be sealed using plugs, covers, sealing wax, cement, or other suitable material that can be readily and completely removed after completion of the test. Sealing materials shall be tracer gas free.

T-1043 TEMPERATURE

The minimum metal temperature for all components during a test shall be as specified in the applicable Mandatory Appendix of this Article or in the referencing Code Section for the hydrostatic, hydropneumatic, or pneumatic test of the pressure component or parts. The minimum or maximum temperature during the test shall not exceed that temperature compatible with the leak testing method or technique used.

T-1044 PRESSURE/VACUUM (PRESSURE LIMITS)

Unless specified in the applicable Mandatory Appendix of this Article or by the referencing Code Section, components that are to be pressure-leak tested shall not be tested at a pressure exceeding 25% of the Design Pressure.

T-1050 PROCEDURE

T-1051 PRELIMINARY LEAK TEST

Prior to employing a sensitive leak testing method, it may be expedient to perform a preliminary test to detect and eliminate gross leaks. This shall be done in a manner that will not seal or mask leaks during the specified test.

T-1052 TEST SEQUENCE

It is recommended that leak testing be performed before hydrostatic or hydropneumatic testing.

T-1060 CALIBRATION

T-1061 PRESSURE/VACUUM GAGES

(a) All dial indicating and recording type gages used shall be calibrated against a standard deadweight tester, a calibrated master gage, or a mercury column, and recalibrated at least once a year, when in use, unless specified differently by the referencing Code Section or Mandatory Appendix. All gages used shall provide results accurate to within the Manufacturer's listed accuracy and shall be recalibrated at any time that there is reason to believe they are in error.

(b) When other than dial indicating or recording type gages are required by an applicable Mandatory Appendix, they shall be calibrated as required by that Mandatory Appendix or referencing Code Section.

T-1062 TEMPERATURE MEASURING DEVICES

When temperature measurement is required by the referencing Code Section or Mandatory Appendix, the device(s) shall be calibrated in accordance with the requirements of that Code Section or Mandatory Appendix.

T-1063 CALIBRATION LEAK STANDARDS

T-1063.1 Reservoir Leak Standard. This standard leak shall have a reservoir of the tracer gas connected to the leak. The leak standard shall

(a) have a leakage rate in the range and tracer gas species specified by the referencing Code Section or, if not specified, per the Mandatory Appendix.

(b) be calibrated with discharge either to vacuum or to an air environment of 1 atm (101 kPa absolute) to match the test application or instrument type.

T-1063.2 Nonreservoir Leak Standard. This standard leak does not have an inherent supply of tracer gas. The leak shall

(a) have a leakage rate in the range and tracer gas species specified by the referencing Code Section or, if not specified, per the Mandatory Appendix.

(b) be calibrated with discharge either to vacuum or to an air environment of 1 atm (101 kPa absolute) to match the test application.

(c) be calibrated at a pressure differential across the leak of 1 atm (14.7 psi, 101 kPa) or at a differential that represents the differential to be used in the specific test procedure.

T-1070 TEST

See applicable Mandatory Appendix of this Article.

T-1080 EVALUATION

T-1081 ACCEPTANCE STANDARDS

Unless otherwise specified in the referencing Code Section, the acceptance criteria given for each method or technique of that method shall apply. The supplemental leak testing equations for calculating leakage rates for the method or technique used are stated in the Mandatory Appendices of this Article.

T-1090 DOCUMENTATION

T-1091 TEST REPORT

The test report shall contain, as a minimum, the following information as applicable to the method or technique:

(a) date of test
(b) certified level and name of operator
(c) test procedure (number) and revision number
(d) test method or technique
(e) test results
(f) component identification
(g) test instrument, standard leak, and material identification
(h) test conditions, test pressure, tracer gas, and gas concentration
(i) gage(s) — manufacturer, model, range, and identification number
(j) temperature measuring device(s) and identification number(s)
(k) sketch showing method or technique setup

T-1092 RECORD RETENTION

The test report shall be maintained in accordance with the requirements of the referencing Code Section.

MANDATORY APPENDIX I
BUBBLE TEST — DIRECT PRESSURE TECHNIQUE

I-1010 SCOPE

The objective of the direct pressure technique of bubble leak testing is to locate leaks in a pressurized component by the application of a solution or by immersion in liquid that will form bubbles as leakage gas passes through it.

I-1020 GENERAL

I-1021 WRITTEN PROCEDURE REQUIREMENTS

I-1021.1 Requirements. The requirements of T-1021.1, Table I-1021, and the following as specified in this Article or referencing Code shall apply.

(a) soak time
(b) pressure gage
(c) test pressure
(d) acceptance criteria

I-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table I-1021 shall apply.

I-1030 EQUIPMENT

I-1031 GASES

Unless otherwise specified, the test gas will normally be air; however, inert gases may be used.

NOTE: When inert gas is used, safety aspects of oxygen deficient atmosphere should be considered.

I-1032 BUBBLE SOLUTION

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. Household soap or detergents are not permitted as substitutes for bubble testing solutions.

(b) The bubble forming solution shall be compatible with the temperature of the test conditions.

I-1033 IMMERSION BATH

(a) Water or another compatible solution shall be used for the bath.

(b) The immersion solution shall be compatible with the temperature of the test conditions.

I-1070 TEST

I-1071 SOAK TIME

Prior to examination the test pressure shall be held for a minimum of 15 min.

(19)

Table I-1021
Requirements of a Direct Pressure Bubble Leak Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Bubble forming solution (Brand name or type)	X	...
Surface temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Surface preparation technique	X	...
Lighting intensity (decrease below that specified in this Article or as previously qualified)	X	...
Personnel performance qualification requirements, when required	...	X
Solution applicator	...	X
Pressurizing gas (air or inert gas)	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

I-1072 SURFACE TEMPERATURE

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (5°C) nor above 125°F (50°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain within the range of 40°F (5°C) to 125°F (50°C) during examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

I-1073 APPLICATION OF SOLUTION

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area. The number of bubbles produced in the solution by application should be minimized to reduce the problem of masking bubbles caused by leakage.

I-1074 IMMERSION IN BATH

The area of interest shall be placed below the surface of the bath in an easily observable position.

I-1075 LIGHTING AND VISUAL AIDS

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

I-1076 INDICATION OF LEAKAGE

The presence of continuous bubble growth on the surface of the material indicates leakage through an orifice passage(s) in the region under examination.

I-1077 POSTTEST CLEANING

After testing, surface cleaning may be required for product serviceability.

I-1080 EVALUATION

I-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

I-1082 REPAIR/RETEST

When leakage is observed, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

MANDATORY APPENDIX II
BUBBLE TEST — VACUUM BOX TECHNIQUE

II-1010 SCOPE

The objective of the vacuum box technique of bubble leak testing is to locate leaks in a pressure boundary that cannot be directly pressurized. This is accomplished by applying a solution to a local area of the pressure boundary surface and creating a differential pressure across that local area of the boundary causing the formation of bubbles as leakage gas passes through the solution.

II-1020 GENERAL

II-1021 WRITTEN PROCEDURE REQUIREMENTS

II-1021.1 Requirements. The requirements of T-1021.1, Table II-1021, and the following as specified in this Article or referencing Code shall apply:

(a) pressure gage

(b) vacuum test pressure

(c) vacuum retention time

(d) box overlap

(e) acceptance criteria

II-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table II-1021 shall apply.

II-1030 EQUIPMENT

II-1031 BUBBLE SOLUTION

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. The number of bubbles contained in the solution should be minimized to reduce the problem of discriminating between existing bubbles and those caused by leakage.

(b) Soaps or detergents designed specifically for cleaning shall not be used for the bubble forming solution.

(c) The bubble forming solution shall be compatible with the temperature conditions of the test.

II-1032 VACUUM BOX

The vacuum box used shall be of convenient size [e.g., 6 in. (150 mm) wide by 30 in. (750 mm) long] and contain a window in the side opposite the open bottom. The open bottom edge shall be equipped with a suitable gasket to form a seal against the test surface. Suitable connections, valves, lighting, and gage shall be provided. The gage shall have a range of 0 psi (0 kPa) to 15 psi (100 kPa), or equivalent pressure units such as 0 in. Hg to 30 in. Hg (0 mm Hg to 750 mm Hg). The gage range limit requirements of T-1031(a) do not apply.

(19)

Table II-1021
Requirements of a Vacuum Box Leak Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Bubble forming solution (Brand name or type)	X	...
Surface temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Surface preparation technique	X	...
Lighting intensity (decrease below that specified in this Article or as previously qualified)	X	...
Personnel performance qualification requirements, when required	...	X
Vacuum box (size and shape)	...	X
Vacuum source	...	X
Solution applicator	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

II-1033 VACUUM SOURCE

The required vacuum can be developed in the box by any convenient method (e.g., air ejector, vacuum pump, or motor intake manifold). The gage shall register a partial vacuum of at least 2 psi (4 in. Hg) (15 kPa) below atmospheric pressure or the partial vacuum required by the referencing Code Section.

II-1070 TEST

II-1071 SURFACE TEMPERATURE

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (5°C) nor above 125°F (50°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain in the range of 40°F (5°C) to 125°F (50°C) during the examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

II-1072 APPLICATION OF SOLUTION

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area before placement of the vacuum box.

II-1073 VACUUM BOX PLACEMENT

The vacuum box shall be placed over the solution coated section of the test surface and the box evacuated to the required partial vacuum.

II-1074 PRESSURE (VACUUM) RETENTION

The required partial vacuum (differential pressure) shall be maintained for at least 10 sec examination time.

II-1075 VACUUM BOX OVERLAP

An overlap of 2 in. (50 mm) minimum for adjacent placement of the vacuum box shall be used for each subsequent examination.

II-1076 LIGHTING AND VISUAL AIDS

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

II-1077 INDICATION OF LEAKAGE

The presence of continuous bubble growth on the surface of the material or weld seam indicates leakage through an orifice passage(s) in the region under examination.

II-1078 POSTTEST CLEANING

After testing, cleaning may be required for product serviceability.

II-1080 EVALUATION

II-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

II-1082 REPAIR/RETEST

When leakage is observed, the location of the leak(s) shall be marked. The vacuum box shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

MANDATORY APPENDIX III
HALOGEN DIODE DETECTOR PROBE TEST

III-1010 INTRODUCTION AND SCOPE

(a) Introduction. The more sophisticated electronic halogen leak detectors have very high sensitivity. These instruments make possible the detection of halogen gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

(b) Scope. The halogen detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

III-1011 ALKALI-ION DIODE (HEATED ANODE) HALOGEN LEAK DETECTORS

The alkali-ion diode halogen detector probe instrument uses the principle of a heated platinum element (anode) and an ion collector plate (cathode), where halogen vapor is ionized by the anode, and the ions are collected by the cathode. A current proportional to the rate of ion formation is indicated on a meter.

III-1012 ELECTRON CAPTURE HALOGEN LEAK DETECTORS

The electron capture halogen detector probe instrument uses the principle of the affinity of certain molecular compounds for low energy free electrons usually produced by ionization of gas flow through an element with a weak radioactive tritium source. When the gas flow contains halides, electron capture occurs causing a reduction in the concentration of halogen ions present as indicated on a meter. Non-electron capturing nitrogen or argon is used as background gas.

III-1020 GENERAL

III-1021 WRITTEN PROCEDURE REQUIREMENTS

III-1021.1 Requirements. The requirements of T-1021.1, Table III-1021, and the following as specified in this Article or referencing Code shall apply.

(a) leak standard
(b) tracer gas
(c) tracer gas concentration
(d) test pressure
(e) soak time
(f) scanning distance
(g) pressure gage
(h) sensitivity verification checks
(i) acceptance criteria

III-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table III-1021 shall apply.

III-1030 EQUIPMENT

III-1031 TRACER GAS

Gases that may be used are shown in Table III-1031.

III-1031.1 For Alkali-Ion Diode. Halogen leak detectors, select a tracer gas from Table III-1031 that will produce the necessary test sensitivity.

III-1031.2 For Electron Capture. Halogen leak detectors, sulfur hexafluoride, SF_6, is the recommended tracer gas.

III-1032 INSTRUMENT

An electronic leak detector as described in III-1011 or III-1012 shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) Meter: a meter on the test instrument, or a probe, or both.

(b) Audio Devices: a speaker or set of headphones that emits audible indications.

(c) Indicator Light: a visible indicator light.

III-1033 CALIBRATION LEAK STANDARDS

A leak standard per T-1063.1 using 100% tracer gas as selected per III-1031.

III-1060 CALIBRATION

III-1061 STANDARD LEAK SIZE

The maximum leakage rate Q for the leak standard described in III-1033 containing 100% tracer concentration for use in III-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s), unless specified otherwise by the referencing Code Section, and %TG is the concentration of the tracer gas (in %) that is to be used for the test (see III-1072).

(19)

Table III-1021
Requirements of a Halogen Diode Detector Probe Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Personnel performance qualification requirements, when required	...	X
Scanning rate (maximum as demonstrated during system calibration)	...	X
Pressurizing gas (air or an inert gas)	...	X
Scanning direction	...	X
Signaling device	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

III-1062 WARM UP

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

III-1063 SCANNING RATE

The instrument shall be calibrated by passing the probe tip across the orifice of the leak standard in III-1061. The probe tip shall be kept within $\frac{1}{8}$ in. (3 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

III-1064 DETECTION TIME

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

Table III-1031
Tracer Gases

Commercial Designation	Chemical Designation	Chemical Symbol
Refrigerant-11	Trichloromonofluoromethane	CCl_3F
Refrigerant-12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant-21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant-22	Chlorodifluoromethane	$CHClF_2$
Refrigerant-114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Refrigerant-134a	Tetrafluoroethane	$C_2H_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6

III-1065 FREQUENCY AND SENSITIVITY

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicates that the detector cannot detect leakage from the leak standard of III-1061, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

III-1070 TEST

III-1071 LOCATION OF TEST

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

III-1072 CONCENTRATION OF TRACER GAS

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

III-1073 SOAK TIME

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the halogen gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with halogen gas.

III-1074 SCANNING DISTANCE

After the required soak time per III-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $^1/_8$ in. (3 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

III-1075 SCANNING RATE

The maximum scanning rate shall be as determined in III-1063.

III-1076 SCANNING DIRECTION

The examination scan should commence in the uppermost portion of the system being leak tested while progressively scanning downward.

III-1077 LEAKAGE DETECTION

Leakage shall be indicated and detected according to III-1032.

III-1078 APPLICATION

The following are two examples of applications that may be used (note that other types of applications may be used).

III-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the uppermost portion of the tubesheet tube rows while progressively scanning downward.

III-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

III-1080 EVALUATION

III-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s).

III-1082 REPAIR/RETEST

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

MANDATORY APPENDIX IV HELIUM MASS SPECTROMETER TEST — DETECTOR PROBE TECHNIQUE

IV-1010 SCOPE

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in pressurized components. The high sensitivity of this leak detector makes possible the detection of helium gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures, or the determination of the presence of helium in any gaseous mixture. The detector probe is a semi-quantitative technique used to detect and locate leaks, and shall not be considered quantitative.

IV-1020 GENERAL

IV-1021 WRITTEN PROCEDURE REQUIREMENTS

IV-1021.1 Requirements. The requirements of T-1021.1, Table IV-1021, and the following as specified in this Article or referencing Code shall apply.

(a) instrument leak standard
(b) system leak standard
(c) tracer gas
(d) tracer gas concentration
(e) test pressure
(f) soak time
(g) scanning distance
(h) pressure gage
(i) sensitivity verification checks
(j) acceptance criteria

IV-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table IV-1021 shall apply.

IV-1030 EQUIPMENT

IV-1031 INSTRUMENT

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) Meter: a meter on, or attached to, the test instrument.

(b) Audio Devices: a speaker or set of headphones that emits audible indications.

(c) Indicator Light: a visible indicator light.

IV-1032 AUXILIARY EQUIPMENT

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Detector Probe. All areas to be examined shall be scanned for leaks using a detector probe (sniffer) connected to the instrument through flexible tubing or a hose. To reduce instrument response and clean up time, the tubing or hose length shall be less than 15 ft (4.5 m), unless the test setup is specifically designed to attain the reduced response and clean up time for longer tubing or hose lengths.

IV-1033 CALIBRATION LEAK STANDARDS

Calibration leak standards shall be per T-1063.1.

IV-1060 CALIBRATION

IV-1061 INSTRUMENT CALIBRATION

IV-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibrated leak standard.

IV-1061.2 Calibration. Calibrate the helium mass spectrometer per the instruments manufacturer's operation and maintenance manual, using a reservoir leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The standard shall have a helium leakage rate in the range of 1×10^{-6} to 1×10^{-10} std cm^3/s (1×10^{-7} to 1×10^{-11} Pa m^3/s), or as recommended by the manufacturer. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

IV-1062 SYSTEM CALIBRATION

IV-1062.1 Standard Leak Size. The maximum leakage rate Q for the leak standard described in IV-1033, containing 100% helium concentration for use in IV-1062.2, shall be calculated as follows:

$$Q = Q_S \frac{\%TG}{100}$$

(19)

Table IV-1021
Requirements of a Helium Mass Spectrometer Detector Probe Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Detector Probe manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Personnel performance qualification requirements, when required	...	X
Pressurizing gas (air or inert gas)	...	X
Scanning rate (maximum as demonstrated during system calibration)	...	X
Signaling device	...	X
Scanning direction	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

where Q_s is 1 × 10^{-4} std cm^3/s (1 × 10^{-5} Pa m^3/s), unless specified otherwise by the referencing Code Section, and %TG is the concentration of the tracer gas (in %) that is to be used for the test (see IV-1072).

IV-1062.2 Scanning Rate. After connecting the detector probe to the instrument, the system shall be calibrated by passing the detector probe tip across the orifice of the leak standard in IV-1062.1. The probe tip shall be kept within $^1\!/_8$ in. (3 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

IV-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

IV-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during the test. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per IV-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested.

IV-1070 TEST

IV-1071 LOCATION OF TEST

The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

IV-1072 CONCENTRATION OF TRACER GAS

The concentration of the helium tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

IV-1073 SOAK TIME

Prior to testing, the test pressure shall be held a minimum of 30 min. The minimum allowable soak time may be less than that specified above due to the immediate dispersion of the helium gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with helium gas.

IV-1074 SCANNING DISTANCE

After the required soak time per IV-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $^1\!/_8$ in. (3 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during test scanning.

IV-1075 SCANNING RATE

The maximum scanning rate shall be as determined in IV-1062.2.

IV-1076 SCANNING DIRECTION

The examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward.

IV-1077 LEAKAGE DETECTION

Leakage shall be indicated and detected according to IV-1031.

IV-1078 APPLICATION

The following are two examples of applications that may be used (note that other types of applications may be used).

IV-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the lowermost portion of the tubesheet tube rows while progressively scanning upward.

IV-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

IV-1080 EVALUATION

IV-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s).

IV-1082 REPAIR/RETEST

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

MANDATORY APPENDIX V
HELIUM MASS SPECTROMETER TEST — TRACER PROBE TECHNIQUE

V-1010 SCOPE

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when tracer probe testing, makes possible the detection and location of helium gas flow from the higher pressure side of very small openings through the evacuated envelope or barrier separating the two regions at different pressures. This is a semiquantitative technique and shall not be considered quantitative.

V-1020 GENERAL

V-1021 WRITTEN PROCEDURE REQUIREMENTS

V-1021.1 Requirements. The requirements of T-1021.1, Table V-1021, and the following as specified in this Article or referencing Code shall apply.

(a) instrument leak standard
(b) system leak standard
(c) tracer gas
(d) vacuum test pressure
(e) vacuum gaging
(f) soak time
(g) scanning distance
(h) sensitivity verification checks
(i) acceptance criteria

V-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table V-1021 shall apply.

V-1030 EQUIPMENT

V-1031 INSTRUMENT

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) Meter: a meter on or attached to the test instrument.

(b) Audio Devices: a speaker or set of headphones that emits audible indications.

(c) Indicator Light: a visible indicator light.

V-1032 AUXILIARY EQUIPMENT

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Auxiliary Pump System. When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) Manifold. A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) Tracer Probe. Tubing connected to a source of 100% helium with a valved fine opening at the other end for directing a fine stream of helium gas.

(e) Vacuum Gage(s). The range of vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

V-1033 SYSTEM CALIBRATION LEAK STANDARD

A nonreservoir, capillary type leak standard per T-1063.2 with a maximum helium leakage rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s) shall be used unless otherwise specified by the referencing Code Section.

V-1060 CALIBRATION

V-1061 INSTRUMENT CALIBRATION

V-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibration leak standard.

V-1061.2 Calibration. Calibrate the helium mass spectrometer per the instruments manufacturer's operation and maintenance manual, using a reservoir type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The standard shall have a helium leakage rate in the range of 1×10^{-6} to 1×10^{-10} std cm^3/s (1×10^{-7} to 1×10^{-11} Pa m^3/s), or as recommended by the manufacturer. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

(19)

Table V-1021
Requirements of a Helium Mass Spectrometer Tracer Probe Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Tracer probe manufacturer and model	X	...
Personnel performance qualification requirements, when required	...	X
Tracer probe flow rate (minimum demonstrated during system calibration)	...	X
Scanning rate (maximum as demonstrated during system calibration)	...	X
Signaling device	...	X
Scanning direction	...	X
Vacuum pumping system	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

V-1062 SYSTEM CALIBRATION

V-1062.1 Standard Leak Size. The calibrated leak standard, as stated in V-1033, shall be attached to the component as far as possible from the instrument connection to the component. The leak standard shall remain open during system calibration.

V-1062.2 Scanning Rate. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated for the test by passing the tracer probe tip across the orifice of the leak standard. The probe tip shall be kept within $^1/_4$ in. (6 mm) of the orifice of the leak standard. For a known flow rate from the tracer probe of 100% helium, the scanning rate shall not exceed that which can detect leakage through the calibration leak standard into the test system.

V-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

V-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per V-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested.

V-1070 TEST

V-1071 SCANNING RATE

The maximum scanning rate shall be as determined in V-1062.2.

V-1072 SCANNING DIRECTION

The examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

V-1073 SCANNING DISTANCE

The tracer probe tip shall be kept within $^1/_4$ in. (6 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during the examination scanning.

V-1074 LEAKAGE DETECTION

Leakage shall be indicated and detected according to V-1031.

V-1075 FLOW RATE

The minimum flow rate shall be as set in V-1062.2.

V-1080 EVALUATION

V-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s).

V-1082 REPAIR/RETEST

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be vented, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

MANDATORY APPENDIX VI
PRESSURE CHANGE TEST

VI-1010 SCOPE

This test method describes the techniques for determining the leakage rate of the boundaries of a closed component or system at a specific pressure or vacuum. Pressure hold, absolute pressure, maintenance of pressure, pressure loss, pressure decay, pressure rise, and vacuum retention are examples of techniques that may be used whenever pressure change testing is specified as a means of determining leakage rates. The tests specify a maximum allowable change in either pressure per unit of time, percentage volume, or mass change per unit of time.

VI-1020 GENERAL

VI-1021 WRITTEN PROCEDURE REQUIREMENTS

VI-1021.1 Requirements. The requirements of T-1021.1, Table VI-1021, and the following as specified in this Article or referencing Code shall apply.

(a) test/vacuum test pressure

(b) soak time

(c) test duration

(d) recording interval

(e) acceptance criteria

VI-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table VI-1021 shall apply.

VI-1030 EQUIPMENT

VI-1031 PRESSURE MEASURING INSTRUMENTS

(a) Gage Range. Dial indicating and recording type gages shall meet the requirements of T-1031(a). Liquid manometers or quartz Bourdon tube gages may be used over their entire range.

(b) Gage Location. The location of the gage(s) shall be that stated in T-1031(b).

(c) Types of Gages. Regular or absolute gages may be used in pressure change testing. When greater accuracy is required, quartz Bourdon tube gages or liquid manometers may be used. The gage(s) used shall have an accuracy, resolution, and repeatability compatible with the acceptance criteria.

VI-1032 TEMPERATURE MEASURING INSTRUMENTS

Dry bulb or dew point temperature measuring instruments, when used, shall have accuracy, repeatability, and resolution compatible with the leakage rate acceptance criteria.

Table VI-1021
Requirements of a Pressure Change Testing Procedure (19)

Requirement	Essential Variable	Nonessential Variable
Pressure or vacuum gage manufacturer and model	X	...
Temperature measuring instrument manufacturer and model, when applicable	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Personnel performance qualification requirements, when required	...	X
Vacuum pumping system, when applicable	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

VI-1060 CALIBRATION

VI-1061 PRESSURE MEASURING INSTRUMENTS

All dial indicating, recording, and quartz Bourdon tube gages shall be calibrated per T-1061(b). The scale of liquid manometers shall be calibrated against standards that have known relationships to national standards, where such standards exist.

VI-1062 TEMPERATURE MEASURING INSTRUMENTS

Calibration for dry bulb and dew point temperature measuring instruments shall be against standards that have known relationships to national standards, where such standards exist.

VI-1070 TEST

VI-1071 PRESSURE APPLICATION

Components that are to be tested above atmospheric pressure shall be pressurized per T-1044.

VI-1072 VACUUM APPLICATION

Components that are to be tested under vacuum shall be evacuated to at least 2 psi (4 in. Hg) (15 kPa) below atmospheric pressure or as required by the referencing Code Section.

VI-1073 TEST DURATION

The test pressure (or vacuum) shall be held for the duration specified by the referencing Code Section or, if not specified, it shall be sufficient to establish the leakage rate of the component system within the accuracy or confidence limits required by the referencing Code Section. For very small components or systems, a test duration in terms of minutes may be sufficient. For large components or systems, where temperature and water vapor corrections are necessary, a test duration in terms of many hours may be required.

VI-1074 SMALL PRESSURIZED SYSTEMS

For temperature stabilization of very small pressurized systems, such as gasket interspaces, where only system (metal) temperature can be measured, at least 15 min shall elapse after completion of pressurization and before starting the test.

VI-1075 LARGE PRESSURIZED SYSTEMS

For temperature stabilization of large pressurized systems where the internal gas temperature is measured after completion of pressurization, it shall be determined that the temperature of the internal gas has stabilized before starting the test.

VI-1076 START OF TEST

At the start of the test, initial temperature and pressure (or vacuum) readings shall be taken and thereafter at regular intervals, not to exceed 60 min, until the end of the specified test duration.

VI-1077 ESSENTIAL VARIABLES

(a) When it is required to compensate for barometric pressure variations, measurement of the test pressure shall be made with either an absolute pressure gage or a regular pressure gage and a barometer.

(b) When it is required by the referencing Code Section, or when the water vapor pressure variation can significantly affect the test results, the internal dew point temperature or relative humidity shall be measured.

VI-1080 EVALUATION

VI-1081 ACCEPTABLE TEST

When the pressure change or leakage rate is equal to or less than that specified by the referencing Code Section, the test is acceptable.

VI-1082 REJECTABLE TEST

When the pressure change or leakage rate exceeds that specified by the referencing Code Section, the results of the test are unsatisfactory. Leak(s) may be located by other methods described in the Mandatory Appendices. After the cause of the excessive pressure change or leakage rate has been determined and repaired in accordance with the referencing Code Section, the original test shall be repeated.

NOTE: For more information regarding this method of testing refer to the following:

(a) 10 CFR 50, Appendix J, *Primary Containment Leakage Testing for Water Cooled Power Reactors*.

(b) ANSI/ANS 56.8-1981, *American National Standard Containment System Leakage Testing Requirements*, published by the American Nuclear Society.

MANDATORY APPENDIX VIII
THERMAL CONDUCTIVITY DETECTOR PROBE TEST

VIII-1010 INTRODUCTION AND SCOPE

(a) Introduction. These instruments make possible the detection of a tracer gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

(b) Scope. The thermal conductivity detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

VIII-1011 THERMAL CONDUCTIVITY LEAK DETECTORS

The thermal conductivity detector probe instrument uses the principle that the thermal conductivity of a gas or gas mixture changes with any change in the concentration(s) of the gas or gas mixture (i.e., the introduction of a tracer gas in the area of a leak).

VIII-1020 GENERAL

VIII-1021 WRITTEN PROCEDURE REQUIREMENTS

VIII-1021.1 Requirements. The requirements of T-1021.1, Table VIII-1021, and the following as specified in this Article or referencing Code shall apply.

(a) leak standard
(b) tracer gas concentration
(c) test pressure
(d) soak time
(e) scanning distance
(f) pressure gage
(g) sensitivity verification checks
(h) acceptance criteria

VIII-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table VIII-1021 shall apply.

VIII-1030 EQUIPMENT

VIII-1031 TRACER GAS

In principle, any gas having a thermal conductivity different from air can be used as a tracer gas. The sensitivity achievable depends on the relative differences of the thermal conductivity of the gases [i.e., background air (air used to zero the instrument) and the sampled air (air containing the tracer gas) in the area of a leak]. Table VIII-1031 lists some of the typical tracer gases used. The tracer gas to be used shall be selected based on the required test sensitivity.

VIII-1032 INSTRUMENT

An electronic leak detector as described in VIII-1011 shall be used. Leakage shall be indicated by one or more of the following signaling devices:

(a) Meter. A meter on the test instrument, or a probe, or both.

(b) Audio Devices. A speaker or sets of headphones that emit(s) audible indications.

(c) Indicator Light. A visible indicator light.

VIII-1033 CALIBRATION LEAK STANDARD

A leak standard per T-1063.2 using 100% tracer gas as selected per VIII-1031.

VIII-1060 CALIBRATION

VIII-1061 STANDARD LEAK SIZE

The maximum leakage rate Q for the leak standard described in VIII-1033 containing 100% tracer concentration for use in VIII-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s [in std cm^3/s (Pa m^3/s)] is the required test sensitivity and %TG is the concentration of the tracer gas (in percent) that is to be used for the test. See VIII-1072.

(19)

Table VIII-1021 Requirements of a Thermal Conductivity Detector Probe Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Tracer gas	X	...
Personnel performance qualification requirements, when required	...	X
Scanning rate (maximum demonstrated during system calibration)	...	X
Signaling device	...	X
Scanning direction	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

VIII-1062 WARM UP

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

VIII-1063 SCANNING RATE

The detector shall be calibrated by passing the probe tip across the orifice of the leak standard in VIII-1061. The probe tip shall be kept within $^1/_2$ in. (13 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

VIII-1064 DETECTION TIME

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

VIII-1065 FREQUENCY AND SENSITIVITY

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicate that the detector cannot detect leakage per VIII-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

Table VIII-1031 Tracer Gases

Designation	Chemical Designation	Chemical Symbol
...	Helium	He
...	Argon	Ar
...	Carbon Dioxide	CO_2
Refrigerant-11	Trichloromonofluoromethane	CCl_3F
Refrigerant-12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant-21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant-22	Chlorodifluoromethane	$CHClF_2$
Refrigerant-114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Refrigerant-134a	Tetrafluoroethane	$C_2H_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6

VIII-1070 TEST

VIII-1071 LOCATION OF TEST

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

VIII-1072 CONCENTRATION OF TRACER GAS

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

VIII-1073 SOAK TIMES

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the tracer gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with tracer gas.

VIII-1074 SCANNING DISTANCE

After the required soak time per VIII-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $^1/_2$ in. (13 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

VIII-1075 SCANNING RATE

The maximum scanning rate shall be as determined in VIII-1063.

VIII-1076 SCANNING DIRECTION

For tracer gases that are lighter than air, the examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward. For tracer gases that are heavier than air, the examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

VIII-1077 LEAKAGE DETECTION

Leakage shall be indicated and detected according to VIII-1032.

VIII-1078 APPLICATION

The following are two examples of applications that may be used (note that other types of applications may be used).

VIII-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube and held for the time period established by demonstration.

VIII-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

VIII-1080 EVALUATION

VIII-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the maximum leakage rate Q, determined per VIII-1061.

VIII-1082 REPAIR/RETEST

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

(19)

MANDATORY APPENDIX IX
HELIUM MASS SPECTROMETER TEST — HOOD TECHNIQUE

IX-1010 SCOPE

The technique described in this Appendix uses the helium mass spectrometer leak detector (HMSLD) to detect and measure helium gas leakage across a boundary under test, into an evacuated space. This technique can typically be used to measure helium leakage rates of 1×10^{-4} atm cm^3/sec to 1×10^{-11} atm cm^3/sec (1×10^{-3} Pa m^3/sec to 1×10^{-10} Pa m^3/sec).

The high sensitivity of this helium hood leakage rate test makes it possible to detect and measure total helium mass flow across a boundary or barrier that separates a space that can be evacuated from a region containing helium gas. This quantitative leakage rate measurement technique makes it possible to determine net leakage rate by distinguishing helium leakage from preexisting background signal.

IX-1020 GENERAL

IX-1021 WRITTEN PROCEDURE REQUIREMENTS

IX-1021.1 Requirements. The requirements of T-1021.1, Table IX-1021, and the following as specified in this Article or referencing Code shall apply.

(a) instrument leak standard

(b) system leak standard

(c) vacuum gaging

(d) acceptance criteria

IX-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table IX-1021 shall apply.

IX-1030 EQUIPMENT

IX-1031 INSTRUMENT

A helium mass spectrometer leak detector shall be used. The instrument output shall be indicated by a meter, light bar, digital display, or other numeric or visually subdivided signal on or attached to the test instrument.

IX-1032 AUXILIARY EQUIPMENT

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Auxiliary Pump System for Split Flow Testing. When the gas load of the test system necessitates the use of an auxiliary vacuum pump system, the test system sensitivity will be affected by the proportional splitting of the gas flow between the mass spectrometer and the auxiliary pump. This technique of testing requires particular attention to attain the required test sensitivity and response time.

Table IX-1021
Requirements of a Helium Mass Spectrometer Hood Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Technique of establishing minimum concentration of tracer gas in the hood	X	...
Technique of evaluating, measuring, or determining the absolute pressure in the hood	...	X
Personnel performance qualification requirements, when required	...	X
Hood materials	...	X
Vacuum pumping system	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

(c) Manifold. A system of pipes and valves with connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) Hood. A permanent or temporary envelope or container that creates a space or volume that is used to maintain a concentration of tracer gas in contact with the upstream surface of the boundary being leak tested. Examples include the following:

(1) a flexible plastic enclosure taped to or around a component

(2) an annular space between concentric vessels

(3) an adjacent volume of a vessel that shares a boundary with an evacuated test space

(e) Vacuum Gage(s). Vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

(f) High-Speed Pump. A high-speed pump may be used in series between the test object and the helium mass spectrometer to reduce the system response time. The high-speed pump may be a turbomolecular, turbodrag, diffusion, or other mass-throughput pump that does not introduce extraneous gas flow to the test system from a source other than the evacuated test space. There is no loss in test sensitivity or reliability when the entire throughput of the in-series pump is directed through the helium mass spectrometer leak detector.

IX-1033 SYSTEM CALIBRATION LEAK STANDARD

(a) Unless otherwise specified by the referencing Code Section, the test system shall include a system calibration leak standard per T-1063.1 with a helium leakage rate between 0.2 and 5 times the acceptance criteria for the test.

(b) Unless otherwise specified by the referencing Code Section, the system calibration leak standard shall be of a helium leakage rate that will cause the mass spectrometer leak detector to be in the same test mode at the system calibration value M_1 as the test mode that will occur at value M_3 if a leak is detected during the test that is equal to the test acceptance criteria.

IX-1050 TECHNIQUE

IX-1051 PERMEATION

When systems with long response times (i.e., low evacuated volume to system pumping speed ratio) are to be tested, helium permeation through nonmetallic seals can lead to false results. In cases like this, it is recommended to locally hood test such seals or exclude them from the hood if the seals are not required to be tested.

IX-1052 REPETITIVE OR SIMILAR TESTS

For repetitive tests or where the test time is known from previous similar tests, the preliminary calibration, per IX-1062.5, may be omitted.

IX-1053 MULTIPLE-MODE MASS SPECTROMETER LEAK DETECTORS

When this leak test is performed with a multiple-mode HMSLD, measures shall be taken to ensure that a change in test mode will not result in an invalid leakage rate measurement. The use of a mode lock throughout the test cycle is permitted.

IX-1060 CALIBRATION

IX-1061 INSTRUMENT CALIBRATION

IX-1061.1 Warm-Up. The instrument shall be turned on and allowed to warm up for at least the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

IX-1061.2 Instrument Range Lock. If an instrument range lock will be used during testing, the range lock shall be engaged prior to calibration of the instrument.

IX-1061.3 Calibration. Calibrate the helium mass spectrometer per the instrument manufacturer's operation and maintenance manual using a leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The standard shall have a helium leakage rate in the range of 1×10^{-6} std cm^3/s to 1×10^{-10} std cm^3/s (1×10^{-7} Pa m^3/s to 1×10^{-11} Pa m^3/s), or as recommended by the manufacturer. The instrument shall have sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

IX-1061.4 Instrument Sensitivity Verification. Perform an instrument sensitivity verification using a calibrated leak to establish that the instrument is at the required sensitivity. The standard shall have a helium leakage rate in the range of 1×10^{-6} atm cm^3/s to 1×10^{-10} atm cm^3/s (1×10^{-7} Pa m^3/s to 1×10^{-11} Pa m^3/s), or as recommended by the manufacturer. The instrument sensitivity for helium may be calculated as follows:

$$\text{instrument sensitivity} = \text{div} \times \frac{\text{CL}}{\text{open} - \text{closed}} \text{ atm cm}^3\text{/s} \left(\text{Pa m}^3\text{/s}\right) \text{ helium}$$

where

CL = helium leakage rate of the instrument calibrated leak standard, atm cm^3/s (Pa m^3/s)

closed = HMSLD-indicated leakage rate with the instrument calibrated leak valve closed (calibrated leak isolated)

div = smallest nominal unit of leakage rate resolution of the HMSLD display with the instrument calibrated leak valve closed (calibrated leak isolated)

open = HMSLD-indicated leakage rate with the instrument calibrated leak valve open

IX-1062 SYSTEM CALIBRATION

IX-1062.1 Standard Leak Size. A calibrated leak (CL) standard as per T-1063.1 with 100% helium shall be attached, where feasible, to the component at the extremity of the conductance path from the instrument connection to the component.

IX-1062.2 Response Time. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated by opening the leak standard to the system. The leak standard shall remain open until the instrument signal becomes stable.

The time shall be recorded when the leak standard is first opened to the component and again when the increase in output signal becomes stable. The elapsed time between the two readings is the response time. This response time shall be noted and recorded. The stable instrument reading shall be noted and recorded as M_1 in divisions.

IX-1062.3 Clean-Up Time. With the test system at equilibrium, and with the system calibrated leak admitted to the system for M_1, the calibrated leak shall be isolated. The time shall be recorded when the leak standard is first isolated and again when the decrease in mass spectrometer leak detector signal becomes stable. The elapsed time between the two readings is the clean-up time. This clean-up time shall be noted and recorded.

IX-1062.4 Background Reading.[22] Background M_2 is established after determining the clean-up time. The leak standard is isolated from the system for this measurement, and the instrument reading M_2 shall be recorded when the MSLD output value is stable.

IX-1062.5 Preliminary Calibration. The preliminary system sensitivity shall be calculated as follows:

$$S_1 = \frac{\text{CL}}{M_1 - M_2} = \text{std cm}^3/\text{s/div} \left(\text{Pa m}^3/\text{s/div} \right)$$

The system calibration shall be repeated when there is any change in the leak detector setup (e.g., a change in the portion of helium bypassed to the auxiliary pump, if used) or any change in the leak standard. The leak standard shall be isolated from the system upon completing the preliminary system sensitivity calibration.

IX-1062.6 Final Calibration. Upon completing the test of the system per IX-1071.6, and with the component still exposed to helium under the hood, the leak standard shall be again opened into the system being tested. The increase in instrument output after a time nominally equal to the response time shall be noted and recorded as M_4 in divisions and used in calculating the final system sensitivity as follows:

$$S_2 = \frac{\text{CL}}{M_4 - M_3} = \text{std cm}^3/\text{s/div} \left(\text{Pa m}^3/\text{s/div} \right)$$

IX-1062.7 Test Reliability — Correlation of Calibration Factors. The value of S_2 shall be within ±30% of S_1. This can be stated as $0.77 \le S_1/S_2 \le 1.43$. If this requirement for test reliability is not met, then the component shall be retested. The test system may be allowed to further vacuum condition, measures to control the environment may be improved, the instrument may be cleaned and/or repaired or recalibrated, or other measures to improve process control may be introduced prior to the component retest.

IX-1070 TEST

IX-1071 STANDARD TECHNIQUE

IX-1071.1 Hood. For a single wall component or part, the hood (envelope) container may be made of a material such as plastic or a rigid material such as a metal or composite material. For component designs that have an inherent hood, the upstream space may be used as the hood.

IX-1071.2 Filling of Hood with Tracer Gas. After completing preliminary calibration per IX-1062.5, the space between the component outer surface and the hood shall be filled with helium.

IX-1071.3 Determining Hood Tracer Gas Concentration. When possible, the tracer gas concentration in the hood enclosure shall be determined by direct concentration measurement with a tracer gas analyzer, inferred from measurement of oxygen concentration, or calculated from pressure measurements.

IX-1071.4 Helium Concentration Sampling Point Location. To the degree possible, when the tracer gas concentration is determined by concentration measurement, the sampling point shall be at an elevation below the lowest portion of the boundary under test.

IX-1071.5 Upstream Pressure Compensation. When the nominal upstream pressure in the hood is substantially less than 1 atm absolute (101 kPa), a hood pressure correction factor, C_{Pres}, shall be calculated for use in IX-1071.7. The hood pressure correction factor, C_{Pres}, is equal to 1 atm (101 kPa), divided by the nominal absolute hood pressure, P_{hood}.

(U.S. Customary Units)

$$C_{\text{Pres}} = \frac{1 \text{ atm}}{P_{\text{hood}} \text{ atm}}$$

(SI Units)

$$C_{Pres} = \frac{101 \text{ kPa}}{P_{hood} \text{ kPa}}$$

NOTE: Other units of absolute pressure may be used for this calculation.

IX-1071.6 Test Duration. After filling the hood with helium, the instrument output, M_3, shall be recorded after waiting for a test time equal to at least the longer of the response time determined in IX-1062.2 or the clean-up time, or if the output signal has not become stable, until the output signal stabilizes.

IX-1071.7 System Measured Leakage Rate. After completing final calibration per IX-1062.6, the system leakage rate shall be determined as follows:

(a) For tests where no change in output signal occurs (i.e., $M_2 = M_3$), the system leakage rate shall be reported as being "below the detectable range of the system" and the item under test passes.

(b) For tests where the output signal (M_3) remains on scale, the leakage rate shall be determined as follows:

$$Q = \frac{S_2 \times (M_3 - M_2) \times C_{Pres} \times 100}{\%TG} \text{ std cm}^3/\text{s} \left(\text{Pa m}^3/\text{s}\right)$$

where %TG is the concentration of the tracer gas (in %) in the hood. See IX-1071.3.

(c) For tests where the output signal (M_3) exceeds the detectable range of the system (i.e., output signal is off scale), the system leakage rate shall be reported as being "greater than the detectable range of the system" and the item under test fails.

IX-1072 ALTERNATIVE TECHNIQUE

IX-1072.1 System Correction Factor. For helium mass spectrometer leak indicator meters in leakage rate units, a System Correction Factor (SCF) may be utilized if it is desired to utilize the indicator meter leakage rate units in lieu of converting the readings to divisions [e.g., the values of M_1, M_2, M_3, and M_4 are directly read from the helium mass spectrometer in atm cm^3/s (Pa m^3/s)].

IX-1072.2 Alternative Formulas. The following equations shall be used in lieu of those described in IX-1062:

(a) Preliminary Calibration (per IX-1062.5). The preliminary system correction factor (PSCF) shall be calculated as follows:

$$\text{PSCF} = \text{CL} / (M_1 - M_2)$$

(b) Final Calibration (per IX-1062.6). The final system correction factor (FSCF) shall be calculated as follows:

$$\text{FSCF} = \text{CL} / (M_4 - M_3)$$

(c) System Measured Leakage Rate (per IX-1071.7). The system leakage rate shall be determined as follows:

$$Q = \frac{\text{FSCF} \times (M_3 - M_2) \times C_{Pres} \times 100}{\%TG} \text{ std cm}^3/\text{s} \left(\text{Pa m}^3/\text{s}\right)$$

(d) Alternate Test Reliability — Correlation of System Correction Factors. The value of the FSCF shall be within ±30% of the PSCF. This can be stated as $0.77 < \text{PSCF/FSCF} \le 1.43$. If this requirement for test reliability is not met, then the component shall be retested. The test system may be allowed to further vacuum condition, measures to control the environment may be improved, the instrument may be cleaned and/or repaired or recalibrated, or other measures to improve process control may be introduced prior to the component retest.

IX-1080 EVALUATION

Unless otherwise specified by the referencing Code Section, the component tested is acceptable when the measured leakage rate Q is equal to or less than 1×10^{-6} atm cm^3/s (1×10^{-7} Pa m^3/s) of helium.

IX-1081 LEAKAGE

When the leakage rate exceeds the permissible value, all welds or other suspected areas may be tested using a tracer probe technique for purposes of locating the leak(s). Leaks may be marked and temporarily sealed to permit completion of the tracer probe location test. The temporary seals shall be of a type that can be readily and completely removed prior to leak repair.

IX-1082 REPAIR/RETEST

If the component is to be repaired, then the leak(s) shall be repaired in accordance with the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

MANDATORY APPENDIX X
ULTRASONIC LEAK DETECTOR TEST

X-1010 INTRODUCTION

This technique describes the use of an ultrasonic leak detector to detect the ultrasonic energy produced by the flow of a gas from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

(a) Due to the low sensitivity [maximum sensitivity of 10^{-2} std cm^3/s (10^{-3} Pa m^3/s)] of this technique, it should not be utilized for the acceptance testing of vessels that will contain lethal or hazardous substances.

(b) This is a semiquantitative method used to detect and locate leaks and shall not be considered quantitative.

X-1020 GENERAL

X-1021 WRITTEN PROCEDURE REQUIREMENTS

X-1021.1 Requirements. The requirements of T-1021.1, Table X-1021, and the following as specified in this Article or referencing Code shall apply.

(a) leak standard
(b) test pressure
(c) soak time
(d) pressure gage
(e) acceptance criteria

X-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table X-1021 shall apply.

X-1030 EQUIPMENT

X-1031 INSTRUMENT

An electronic ultrasonic leak detector capable of detecting acoustic energy in the range of 20 to 100 kHz shall be utilized. Leakage shall be indicated by one or more of the following signaling devices:

(a) meter: a meter on the test instrument, or a probe, or both.

(b) audio device: a set of headphones that emit(s) audible indications.

X-1032 CAPILLARY CALIBRATION LEAK STANDARD

A nonreservoir, capillary type leak standard per Article 10, T-1063.2.

Table X-1021
Requirements of an Ultrasonic Leak Testing Procedure

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Pressurizing gas	X	...
Personnel performance qualification requirements, when required	X	...
Scanning distance (maximum demonstrated during system calibration)	...	X
Scanning rate (maximum demonstrated during system calibration)	...	X
Signaling device	...	X
Scanning direction	...	X
Post testing cleaning technique	...	X
Personnel qualification requirements	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

X-1060 CALIBRATION

X-1061 STANDARD LEAK SIZE

The maximum leakage rate Q for the leak standard in X-1032 shall be 1 × 10^{-1} std cm^3/s (1 × 10^{-2} Pa m^3/s), unless otherwise specified by the referencing Code Section.

X-1062 WARM UP

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibration.

X-1063 SCANNING RATE

The leak standard shall be attached to a pressure regulated gas supply and the pressure set to that to be used for the test. The detector shall be calibrated by directing the detector/probe towards the leak standard at the maximum scanning distance to be utilized during testing and noting the meter deflection and/or pitch of the audible signal as the detector/probe is scanned across the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard.

X-1064 FREQUENCY AND SENSITIVITY

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be verified before and after testing, and at intervals of not more than 4 hr during testing. During any verification check, should the meter deflection or audible signal indicate that the detector/probe cannot detect leakage per X-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

X-1070 TEST

X-1071 LOCATION OF TEST

The component to be tested shall, if possible, be removed or isolated from other equipment or structures that could generate ambient or system noise that can drown out leaks.

X-1072 SOAK TIME

Prior to testing, the test pressure shall be held a minimum of 15 min.

X-1073 SCANNING DISTANCE

After the required soak time per X-1072, the detector shall be passed over the test surface. The scanning distance shall not exceed that utilized to determine the maximum scanning rate in X-1063.

X-1074 SCANNING RATE

The maximum scanning rate shall be as determined in X-1063.

X-1075 LEAKAGE DETECTION

Leakage shall be indicated and detected according to X-1031.

X-1080 EVALUATION

X-1081 LEAKAGE

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1 × 10^{-1} std cm^3/s (1 × 10^{-2} Pa m^3/s).

X-1082 REPAIR/RETEST

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

(19)

MANDATORY APPENDIX XI
HELIUM MASS SPECTROMETER — HELIUM-FILLED-CONTAINER LEAKAGE RATE TEST

XI-1010 SCOPE

This technique describes the use of a helium mass spectrometer leak detector (HMSLD) to detect and measure minute traces of helium gas from a helium-filled container into an evacuated volume. The evacuated volume may be a test fixture, test device, or permanent feature of the structure being tested.

XI-1020 GENERAL

This technique detects and measures a helium gas flow from the upstream (higher pressure) side of a boundary or barrier that separates a helium-containing volume from a region or volume that does not intentionally contain helium.

This is a quantitative measurement technique. This technique will result in a small overstatement of leakage rate, creating a confident upper bound measurement of total leakage rate for the boundary being tested.

This technique is particularly advantageous for leak testing sealed objects that contain helium as a condition of service, or that have helium sealed inside prior to the leak test.

This helium-filled-container leakage rate test may be of particular advantage for detection and leakage rate measurement of a torturous path leak.

This technique is typically limited to testing boundaries that do not include elastomers or other materials that have a high helium permeability rate.

XI-1021 WRITTEN PROCEDURE REQUIREMENTS

XI-1021.1 Requirements. The requirements of T-1021.1, Table XI-1021.1-1 , and the following as specified in this Appendix or the referencing Code shall apply:

(a) instrument leak standard

(b) system leak standard

(c) vacuum gaging (if required by the referencing Code)

(d) acceptance criteria

XI-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table XI-1021.1-1 shall apply.

XI-1030 EQUIPMENT

XI-1031 INSTRUMENT

An HMSLD capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by a meter, digital display, or light bar on or attached to the test instrument.

XI-1032 AUXILIARY EQUIPMENT

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations that would interfere with the test.

(b) Manifold. A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(c) Evacuated Envelope. A volume including the downstream surface of the boundary to be tested, and permanent or temporary boundaries and seals that complete the envelope to facilitate the necessary vacuum pressure in the volume.

(d) Vacuum Gage(s). Absolute pressure (vacuum) gage(s) capable of measuring the absolute pressure required in the downstream evacuated volume for the leakage rate test. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

XI-1033 SYSTEM CALIBRATION LEAK STANDARD

(a) Unless otherwise specified by the referencing Code Section, the test system shall include a system calibration leak standard per T-1063.1 with a helium leakage rate between 0.2 and 5 times the acceptance criteria.

(b) Unless otherwise specified by the referencing Code Section, the system calibration leak standard shall be of a helium leakage rate that will cause the leak detector to be in the same test mode at the system calibration with the leak admitted to the system as it would be if the leakage rate measurement was at the acceptance criteria upper leakage rate limit.

Table XI-1021.1-1
Requirements of a Helium Mass Spectrometer Sealed-Object Leakage Rate Test

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Surface preparation technique	X	...
Metal temperature [Note (1)] (change to outside the range specified in this Article or as previously qualified)	X	...
Minimum upstream partial pressure of tracer gas, and minimum total upstream pressure	X	...
Maximum downstream total pressure	X	...
HMSLD test mode at the recording of the HMSLD readings (e.g., R_1, R_2, and R_3)	X	...
Technique of establishing or determining the partial pressure of the tracer gas upstream	...	X
Method of measuring or demonstrating adequacy of the downstream pressure	...	X
Method of ensuring that the upstream tracer gas will not be exhausted during the test	...	X
Post-testing cleaning technique (if any)	...	X
Personnel qualification requirements	...	X
Method of ensuring that the HMSLD mode of operation during leakage rate measurement is the same as during system calibration	...	X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydrostatic, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

XI-1050 TECHNIQUE

XI-1051 HELIUM DEPLETION

The test procedure shall include measures that prevent depletion of the upstream helium supply that would conceal an unacceptable leak.

XI-1052 MULTIPLE-MODE MASS SPECTROMETER LEAK DETECTORS

When this leak test is performed with a multiple-mode HMSLD, measures shall be taken to ensure that a change in test mode will not result in an invalid leakage rate measurement. The use of a mode lock throughout the test cycle is permitted.

XI-1053 TRACER GAS SUPPLY IN THE UPSTREAM VOLUME

XI-1053.1 Filling of the Upstream Volume With Tracer Gas. The upstream volume shall be filled with helium to the specified pressure and concentration prior to beginning the system calibration and leak testing sequence. If placing the helium in the test article is to be performed by the leak testing operator, then the method of achieving the specified partial pressure of tracer gas, and the total upstream pressure shall be detailed in the procedure. If placement of the helium in the test article is performed and documented by personnel other than the leak testing operator, then the identity of the person certifying the helium filling to the leak test operator shall be recorded in the leak test report.

XI-1053.2 Mixed Gases in the Upstream Volume. The use of helium concentrations of less than 99% helium in the upstream volume shall be considered and evaluated for the potential consequences of tracer gas stratification.

XI-1053.3 Determining Tracer Gas Concentration. The tracer gas concentration in the upstream volume shall be measured with a tracer gas analyzer or calculated from pressure measurements where

$$\%\text{He} = 100 \times \frac{\text{partial pressure of helium in the volume}}{\text{total absolute upstream pressure}}$$

XI-1060 CALIBRATION

XI-1061 INSTRUMENT CALIBRATION

XI-1061.1 Warm-Up. The instrument shall be turned on and allowed to warm up for at least the minimum time specified by the instrument manufacturer prior to calibrating the instrument with the leak standard.

XI-1061.2 Instrument Range Lock. If an instrument range lock will be used during testing, the range lock shall be engaged prior to calibration of the instrument.

XI-1061.3 Calibration. Calibrate the HMSLD per the instrument manufacturer's operation and maintenance manual using a reservoir-type leak standard as stated in T-1063.1.

XI-1061.4 Instrument Sensitivity Verification.. Perform an instrument sensitivity verification using a calibrated leak to establish that the instrument is at adequate sensitivity. The standard shall have a helium leakage rate in the range of 1×10^{-6} std cm^3/s to 1 ×

10^{-10} std cm^3/s (1×10^{-7} Pa m^3/s to 1×10^{-11} Pa m^3/s), or as recommended by the manufacturer. The instrument sensitivity for helium leakage rate shall be numerically less than one-tenth (0.1×) the test acceptance criteria.

NOTE: A numerically smaller value for sensitivity represents a greater degree of sensitivity.

$$\text{Instrument sensitivity} = \text{div}\frac{\text{CL}}{\text{open} - \text{closed}}\ \text{atm cm}^3/\text{s}\left(\text{Pa m}^3/\text{s}\right)\ \text{helium}$$

where

CL = helium leakage rate of the instrument calibrated leak standard
closed = HMSLD-indicated leakage rate with the instrument calibrated leak valve closed (calibrated leak isolated)
div = smallest nominal unit of leakage rate resolution of the HMSLD display with the instrument calibrated leak valve closed (calibrated leak isolated)
open = HMSLD-indicated leakage rate with the instrument calibrated leak valve open

XI-1062 TEST SEQUENCE AND SYSTEM CALIBRATION — STANDARD TECHNIQUE

XI-1062.1 Standard Leak. A helium calibrated leak (CL) standard, as per T-1063.1, shall be attached to the evacuated volume. Where feasible, the CL shall be connected to the evacuated volume as far as possible from the instrument connection point.

XI-1062.2 Initial Evacuation and Calibration Reading. Perform the initial evacuation with the system CL open to the system. Monitor the indicated leakage rate, and record the stable leakage rate indication of the HMSLD as value R_1. The evacuation time from the initiation of vacuum pumping until the recording of R_1 may be limited by the procedure.

XI-1062.3 Background and Leakage Rate Reading. Isolate the system calibrated leak from the system and monitor the HMSLD-indicated leakage rate. Record the stable leakage rate indication of the HMSLD as value R_2.

XI-1062.4 Preliminary Calibration. The preliminary system correction factor (PSCF) shall be calculated as follows:

$$\text{PSCF} = \frac{\text{CL}}{R_1 - R_2}\text{(this is a unitless ratio)}$$

XI-1062.5 Final Calibration.

(a) Upon recording of value R_2, the system calibrated leak shall be reopened to the test system.

(b) The stable HMSLD reading following readmission of the system calibrated leak shall be recorded as value R_3.

(c) The final system correction factor (FSCF) shall be calculated as follows:

$$\text{FSCF} = \frac{\text{CL}}{R_3 - R_2}\text{(this is a unitless ratio)}$$

XI-1062.6 Uncorrected System Measured Leakage Rate. After completing final calibration per XI-1062.5, the leakage rate of helium across the boundary with the existing helium upstream partial pressure shall be calculated as follows:

$$Q = \text{FSCF} \times R_2\ \text{atm cm}^3/\text{s}\left(\text{Pa m}^3/\text{s}\right)\ \text{helium}$$

XI-1063 TEST SEQUENCE AND SYSTEM CALIBRATION — ALTERNATIVE SEQUENCE FOR SMALL UPSTREAM VOLUME

XI-1063.1 Alternative Technique. Articles with small upstream volume may be tested by this alternative technique. A system helium calibrated leak standard, i.e., a system CL as per T-1063.1, shall be attached to the evacuated volume. Where feasible, the system CL shall be connected to the evacuated volume as far as possible from the instrument connection point. The initial evacuation is performed with the system helium calibrated leak standard, i.e., the CL, isolated and separately vacuum pumped.

XI-1063.2 Vacuum Conditioning of the System Calibrated Leak. The system helium calibrated leak standard, i.e., the system CL, shall be vacuum pumped by an auxiliary vacuum immediately prior to admission of the system CL to the test system. This auxiliary vacuum pump shall be isolated immediately prior to admission of the system CL to the test system.

XI-1063.3 Initial Evacuation and Calibration Reading. Perform the initial evacuation of the downstream volume with the system CL isolated from the downstream volume. Monitor the indicated leakage rate, and record the stable leakage rate indication of the HMSLD as value R_A. The evacuation time from the initiation of vacuum pumping until the recording of R_A may be limited by the procedure to prevent helium depletion of the upstream volume.

XI-1063.4 Background and Leakage Rate Reading. Isolate the system calibrated leak vacuum pump, and promptly admit the system calibrated leak to the downstream volume by opening a valve. Monitor the indicated leakage rate, and record the stable leakage rate indication of the HMSLD as value R_B.

XI-1063.5 Preliminary Calibration — Alternative Sequence. The alternative preliminary system correction factor (PSCF) shall be calculated as follows:

$$\text{PSCF} = \frac{\text{CL}}{R_B - R_A}\text{(this is a unitless ratio)}$$

XI-1063.6 Final Calibration — Alternative Sequence.

(a) Upon recording of value R_B, the system calibrated leak shall be isolated from the test system.

(b) The stable HMSLD reading following isolation of the system calibrated leak shall be recorded as value R_C.

(c) The alternative final system correction factor (FSCF) shall be calculated as follows:

$$\text{FSCF} = \frac{\text{CL}}{R_C - R_B}\text{(this is a unitless ratio)}$$

XI-1063.7 Uncorrected System Measured Leakage Rate. After completing final calibration per XI-1063.6, the leakage rate of helium across the boundary with the existing helium upstream partial pressure shall be calculated as follows:

$$Q = \text{FSCF} \times R_A \text{ atm cm}^3\text{/s} \left(\text{Pa m}^3\text{/s}\right) \text{ helium}$$

XI-1070 CALCULATION OF TEST RELIABILITY AND CORRECTED LEAKAGE RATE

XI-1071 TEST RELIABILITY

XI-1071.1 Calculation of Test Reliability Ratio. The value of FSCF shall be within ±30% of PSCF. This can be stated as

$$0.77 \le \frac{\text{PSCF}}{\text{FSCF}} \le 1.43$$

If this requirement for test reliability is not met, then the test shall be evaluated for possible helium depletion.

XI-1071.2 Failure of Test Reliability Due to Helium Depletion. If the cause of an unacceptable test reliability ratio is helium depletion, then the product has an unacceptable leakage rate across the boundary, and the test report shall be marked to indicate an unacceptable leakage rate.

XI-1071.3 Unacceptable Test Reliability Ratio Not Due to Helium Depletion. If the cause of an unsatisfactory test reliability ratio is not helium depletion, then the component shall be retested. Measures to control the environment may be improved, the instrument may be cleaned and/or repaired and recalibrated, or other measures may be taken to improve process control.

XI-1072 CALCULATION AND REPORT OF CORRECTED LEAKAGE RATES

XI-1072.1 Off-Scale Leakage Rates. For tests where the output signal (R_2 or R_A) exceeds the detectable range of the system (i.e., the output signal is off-scale), the system leakage rate shall be reported as being "greater than the detectable range of the system" and the item under test fails.

XI-1072.2 Leakage Rate Correction to 1 atm Differential.

(a) If the referencing Code Section requires the helium leakage rate to be stated as equivalent to a leakage rate from 1 atm absolute helium upstream pressure to vacuum (i.e., less than 0.01 atm absolute) downstream, the corrected leakage rate is equal to

$$Q_{@\ 1\text{ atm He}} = Q \times \frac{1\text{ atm}}{\text{partial pressure of helium upstream, atm}} \text{atm cm}^3\text{/s} \left(\text{Pa m}^3\text{/s}\right) \text{ helium}$$

(b) Where helium concentration is less than 100%, the partial pressure of helium upstream shall be calculated as

$$\text{partial pressure of He} = \frac{\text{\%He} \times \text{total upstream pressure, atm}}{100}$$

XI-1072.3 Leakage Rates to be Reported "As-Found". If the referencing Code Section requires the helium leakage rate to be stated with the upstream helium pressure as it exists at the time of the test, then the leakage rate to be reported is equal to the value Q as calculated from the standard test sequence or the alternative test sequence in XI-1063.

XI-1080 EVALUATION

Unless otherwise specified by the referencing Code Section, the component tested is acceptable when the leakage rate of interest is equal to or less than 1×10^{-6} atm cm^3/s (1×10^{-7} Pa m^3/s) of helium.

XI-1081 LEAKAGE

When the leakage rate exceeds the permissible value, all welds or other suspected areas may be retested for leak location using a detector probe technique.

XI-1082 REPAIR/RETEST

If the test article is to be repaired, the leak(s) shall be repaired as required by the referencing Code Section. After repairs have been made and the helium partial pressure in the upstream volume is re-established, the repaired area or areas shall be retested in accordance with the requirements of this Appendix and the referencing Code Section.

NONMANDATORY APPENDIX A SUPPLEMENTARY LEAK TESTING EQUATION SYMBOLS

A-1010 APPLICABILITY OF THE FORMULAS

(a) The equations in this Article provide for the calculated leak rate(s) for the technique used.

(b) The symbols defined below are used in the equations of the appropriate Appendix.

(1) System sensitivity calculation:

S_1 = preliminary sensitivity (calculation of sensitivity), std cm^3/s/div (Pa m^3/s/div)
S_2 = final sensitivity (calculation of sensitivity), std cm^3/s/div (Pa m^3/s/div)

(2) System measured leakage rate calculation:

Q = measured leakage rate of the system (corrected for tracer gas concentration), std cm^3/s (Pa m^3/s)

(3) System Correction Factors:

PSCF = preliminary system correction factor
FSCF = final system correction factor

(4) Tracer gas concentration:

%TG = concentration of Tracer Gas, %

(5) Calibrated standard:

CL = calibrated leak leakage rate, std cm^3/s (Pa m^3/s)

(6) Instrument reading sequence:

M_1 = meter reading before test with calibrated leak open to the component [divisions, or std cm^3/s (Pa m^3/s)]
M_2 = meter reading before test with calibrated leak closed to component [divisions, or std cm^3/s (Pa m^3/s)] (system background noise reading)
M_3 = meter reading (registering component leakage) with calibrated leak closed [divisions, or std cm^3/s (Pa m^3/s)]
M_4 = meter reading (registering component leakage) with calibrated leak open [divisions, or std cm^3/s (Pa m^3/s)]

ARTICLE 11
ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

T-1110 SCOPE

(a) This Article describes or references requirements which are to be used in applying acoustic emission (AE) examination of new and inservice fiber reinforced plastic (FRP) vessels under pressure, vacuum, or other applied loads.

(b) Unless otherwise specified by the referencing Code Section, the maximum test pressure shall not exceed the maximum allowable working pressure (MAWP). Vacuum testing can be full design vacuum. These values are subordinate to stress values in specific procedures outlined in Section X, Part RT, Rules Governing Testing, of the ASME Boiler and Pressure Vessel Code.

(c) This Article is limited to vessels with glass or other reinforcing material contents greater than 15% by weight.

T-1120 GENERAL

(a) When this Article is specified by a referencing Code Section, the method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are found in Article 1, Mandatory Appendix I.

(b) Discontinuities located with AE shall be evaluated by other methods, e.g., visual, ultrasonic, liquid penetrant, etc., and shall be repaired and retested as appropriate.

(c) Additional information may be found in SE-1067/SE-1067M, Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels.

T-1121 VESSEL CONDITIONING

For tanks and pressure vessels that have been stressed previously, the operating pressure and/or load shall be reduced prior to testing according to the schedule shown in Table T-1121. In order to properly evaluate the AE examination, the maximum operating pressure or load on the vessel during the past year must be known, and recorded.

Table T-1121 is used as follows. The reduced pressure is divided by the maximum operating pressure and the quantity is expressed as a percent. This value is entered in the first column and the corresponding row in the second column shows the time required at the reduced pressure, prior to making an AE test. When the ratios fall between two values in the second column the higher value is used.

T-1122 VESSEL LOADING

Arrangements shall be made to load the vessel to the design pressure. The rate of application of load shall be sufficient to expedite the examination with the minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure and/or load at designated checkpoints.

(a) Atmospheric Vessels. Process liquid is the preferred fill medium for atmospheric vessels. If water must replace the process liquid, the designer and user shall be in agreement on the procedure to achieve acceptable load levels.

(b) Vacuum Vessel Loading. A controllable vacuum pump system is required for vacuum tanks.

(c) Pressure Vessel Loading. Water is the preferred test fluid for fiber reinforced pressure vessels. Pressure can be controlled by raising and lowering the liquid level and/or by application of a gas pressure.

Table T-1121
Requirements for Reduced Operating Level Immediately Prior to Examination

Percent of Operating Maximum Pressure and/or Load	Time Spent at Percent of Maximum Pressure and/or Load
10 or less	12 hr
20	18 hr
30	30 hr
40	2 days
50	4 days
60	7 days

GENERAL NOTE: As an example, for an inservice vessel, two factors must be known prior to making a test:
(1) The maximum operating pressure or load during the past year
(2) The test pressure
For new pressure vessel acceptance testing, the "maximum pressure" is the pressure/load seen at the lowest point on the vessel.

T-1123 VESSEL SUPPORT

All vessels shall be examined in their operating position and supported in a manner consistent with good engineering practice. Flat bottomed vessels examined in other than the intended location shall be mounted on a noise-isolating pad on a concrete base or equivalent during the examination.

As an alternative, vessels may be tested in an orientation different from their operating position as long as it can be shown that the test loads are sufficient to achieve the desired maximum stress levels that result from the loading described in T-1173.

T-1124 ENVIRONMENTAL CONDITIONS

The minimum acceptable vessel wall temperature is 40°F (5°C) during the examination. The maximum vessel wall temperature shall not exceed the design operating temperature. Evaluation criteria are based above 40°F (5°C). For vessels designed to operate above 120°F (50°C), the test fluid shall be within 10°F (5°C) of the design operating temperature. Sufficient time shall be allowed before the start of the test for the temperature of the vessel shell and the test fluid to reach equilibrium.

T-1125 NOISE ELIMINATION

Noise sources in the test frequency and amplitude range, such as rain, spargers, and foreign objects contacting the vessels, must be minimized since they mask the AE signals emanating from the structure. The filling inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, i.e., below the liquid level.

T-1126 INSTRUMENTATION SETTINGS

Settings shall be determined as described in Mandatory Appendix II of this Article.

T-1127 SENSORS

(a) Sensor Mounting. The location and spacing of the sensor are in T-1162. The sensors shall be placed in the designated locations with the couplant specified in the testing procedure between the sensor and test article. Assure that adequate couplant is applied. The sensor shall be held in place utilizing methods of attachment which do not create extraneous signals, as specified in the test procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method shall provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or causing loss of coupling.

(b) Surface Contact. Sensors shall be mounted directly on the vessel surface, or integral waveguides shall be used. (Possible signal losses may be caused by coatings such as paint and encapsulants, as well as by construction surface curvature and surface roughness at the contact area.)

(c) High and Low Frequency Channels. An AE instrument channel is defined as a specific combination of sensor, preamplifier, filter, amplifier, and cable(s). High and low frequency channels shall be used for detection and evaluation of AE sources. High frequency channels shall be used for detection and evaluation of AE sources. Low frequency channels may be used to evaluate the coverage by high frequency sensors.

(d) High Frequency Sensors. (See Article 11, Mandatory Appendix I, I-1111.) Several high frequency channels shall be used for zone location of emission sources. This is due to greater attenuation at higher frequencies.

(e) Low Frequency Sensors. (See Article 11, Mandatory Appendix I, I-1112.) If the low frequency sensor option is selected, at least two low frequency channels shall be used. If significant activity is detected on the low frequency channels and not on high frequency channels, high frequency sensor location shall be evaluated by the examiner.

T-1128 PROCEDURE REQUIREMENTS

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material and configurations to be examined including dimensions and product form

(b) method for determination of sensor locations

(c) sensor locations

(d) couplant

(e) method of sensor attachment

(f) sensor type, frequency, and locations

(g) acoustic emission instrument type and frequency

(h) description of system calibration

(i) data to be recorded and method of recording

(j) report requirements

(k) post-examination cleaning

(l) qualification of the examiner(s)

T-1130 EQUIPMENT

(a) The AE system consists of sensors, signal processing, display, and recording equipment. (See Mandatory Appendix I.)

(b) The system shall be capable of recording AE counts, duration (see SE-1067), peak amplitude, and AE events above a threshold within a frequency range of 25 kHz to 300 kHz (if both high and low frequency sensors are used) or 100 kHz to 300 kHz (if only high frequency sensors are used) and have sufficient channels to localize AE sources.

NOTE: Event detection is required for each channel.

Amplitude distributions (using the peak amplitude) are recommended for flaw characterization. Duration criteria per SE-1067 may replace the Counts criteria if specified by the referencing Code Section. The AE system is further described in Mandatory Appendix I.

(c) Capability for measuring time and pressure shall be provided and recorded. The pressure and/or vacuum (in the vessel) shall be continuously monitored to an accuracy of ±2% of the maximum test pressure.

T-1160 CALIBRATION

T-1161 SYSTEM CALIBRATION

See Mandatory Appendix II.

(a) Attenuation Characterization. Typical signal propagation losses shall be determined according to one of the following techniques. These techniques provide a relative measure of the attenuation. The peak amplitude from a pencil break may vary with surface hardness, resin condition, fiber orientation, and cure.

(b) For acoustic emission instrumentation with amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and locate points at distances of 6 in. (150 mm) and 12 in. (300 mm) from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points at 6 in. (150 mm) and 12 in. (300 mm) along a line inclined 45 deg to the direction of the original points. At each of the four points, break 0.3 mm 2H pencil leads and record peak amplitude. A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. This amplitude data from successive lead breaks shall be part of the report.

(c) For systems without amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and break 0.3 mm pencil leads along a line parallel to one of the principal directions of the surface fibers.

Record the distances from the center of the sensor at which the recorded amplitude equals the reference amplitude and the threshold of acoustic emission detectability (see Mandatory Appendix II). Repeat this procedure along a line inclined 45 deg to the direction of the original line. This distance data shall be part of the report.

T-1162 SENSOR LOCATIONS AND SPACINGS

Locations on the vessel shell are determined by the need to detect structural flaws at critical sections, e.g., high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. High frequency sensor spacings are governed by the attenuation of the FRP material. Sensor location guidelines for typical tank types are given in Nonmandatory Appendix A.

(a) Sensor Spacing. The recommended high frequency sensor spacing on the vessel shall be not greater than three times the distance at which the recorded amplitude from the attenuation characterization equals the threshold of detectability (see Mandatory Appendix II). Low frequency sensors shall be placed in areas of low stress and at a maximum distance from one another.

T-1163 SYSTEMS PERFORMANCE CHECK

(a) Sensor Coupling and Circuit Continuity Verification. Verification shall be performed following sensor mounting and system hookup and immediately following the test. A record of the verifications shall be recorded in the report.

(b) Peak Amplitude Response. The peak amplitude response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source shall be taken and recorded following sensor mounting. The peak amplitude of the simulated event at a specific distance greater than 3 in. (75 mm) from each sensor shall not vary more than 6 dB from the average of all the sensors.

(c) Posttest verification using the procedure in (b) shall be done and recorded for the final report.

T-1170 EXAMINATION

T-1171 GENERAL GUIDELINES

The vessel is subjected to programmed increasing load levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

Rates of filling and pressurization shall be controlled so as not to exceed the strain rate specified by the referencing Code Section.

The desired pressure will be attained with a liquid. Pressurization with a gas (air, N_2, etc.) is not permitted. A suitable manometer or other type gage shall be used to monitor pressure. Vacuum shall be attained with a suitable vacuum source.

A quick-release valve shall be provided to handle any potential catastrophic failure condition.

T-1172 BACKGROUND NOISE

Background noise should be identified, minimized, and recorded.

(a) Background Noise Check Prior to Loading. AE monitoring of the vessel is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to loading the vessel. A recommended monitoring period is 10 min to 30 min. If background noise is excessive, the source of the noise shall be eliminated or the examination terminated.

(b) Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include liquid splashing into a vessel; a fill rate that is too high; pumps, motors, agitators, and other mechanical devices; electromagnetic interference; and environment (rain, wind, etc.).

T-1173 LOADING

(a) Atmospheric Vessel Loading. Loading sequences for new atmospheric vessels and vacuum vessels are shown in Figures T-1173(a)(1) and T-1173(a)(2). The test algorithm-flowchart for this class of vessels is given in Figure T-1173(a)(3).

(b) Pressure Vessel Loading. Pressure vessels which operate with superimposed pressures greater than 15 psi (100 kPa) above atmospheric shall be loaded as shown in Figure T-1173(b)(1). The test algorithm flowchart for this class of tanks is given in Figure T-1173(b)(2).

(c) For all vessels, the final load hold shall be for 30 min. The vessel should be monitored continuously during this period.

T-1174 AE ACTIVITY

If significant [see T-1183(b)] AE activity is detected during the test on low frequency channels, and not on high frequency channels, the examiner may relocate the high frequency channels.

T-1175 TEST TERMINATION

Departure from a linear count/load relationship shall signal caution. If the AE count rate increases rapidly with load, the vessel shall be unloaded and the test terminated. [A rapidly (exponentially) increasing count rate indicates uncontrolled continuing damage and is indicative of impending failure.]

T-1180 EVALUATION

T-1181 EVALUATION CRITERIA

The acoustic emission criteria shown in Table T-1181 are set forth as a basis for assessing the severity of structural flaws in FRP vessels. These criteria are based only on high frequency sensors. Low frequency sensors (if used) are used to monitor the entire vessel.

T-1182 EMISSIONS DURING LOAD HOLD, E_H

The criterion based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold.

T-1183 FELICITY RATIO DETERMINATION

The felicity ratio is obtained directly from the ratio of the load at onset of emission and the maximum prior load. The felicity ratio is not measured during the first loading of pressure, atmospheric, or vacuum vessels.

(a) During the first loading of FRP vessels, the felicity ratio is measured from the unload/reload cycles. For subsequent loadings, the felicity ratio is obtained directly from the ratio of the load at onset of emission and the previous maximum load. A secondary felicity ratio is determined from the unload/reload cycles.

(b) The criterion based on felicity ratio is important for inservice vessels. The criterion provides a measure of the severity of previously induced damage. The onset of "significant" emission is used for determining measurement of the felicity ratio, as follows:

(1) more than 5 bursts of emission during a 10% increase in load;

(2) more than $N_c/25$ counts during a 10% increase in load, where N_c is the count criterion defined in Appendix II-1140;

(3) emission continues at a load hold. For the purpose of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

T-1184 HIGH AMPLITUDE EVENTS CRITERION

The high amplitude events criterion is often associated with fiber breakage and is indicative of major structural damage in new vessels. For inservice and previously stressed vessels, emissions during a stress hold and felicity ratio are important.

T-1185 TOTAL COUNTS CRITERION

The criteria based on total counts are valuable for pressure or atmospheric and vacuum vessels. Pressure vessels, particularly during first stressing, tend to be noisy.

Excessive counts, as defined in Table T-1181, are important for all vessels, and are a warning of impending failure.

T-1190 DOCUMENTATION

T-1191 REPORT

The report shall include the following:

(a) complete identification of the vessel, including material type, source, method of fabrication, Manufacturer's name and code number, and previous history of maintenance, as well as relaxation operation data from Table T-1121, prior to testing

(b) vessel sketch or Manufacturer's drawing with dimensions and sensor locations

(c) test liquid employed

(d) test liquid temperature

(e) test sequence — load rate, hold times, and hold levels

(f) correlation of test data with the acceptance criteria

(g) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria

(h) any unusual effects or observations during or prior to the test

(i) date(s) of test

(j) name(s) and qualifications of the test operator(s)

(k) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, system gain, etc.

T-1192 RECORD

(a) A permanent record of AE data includes:

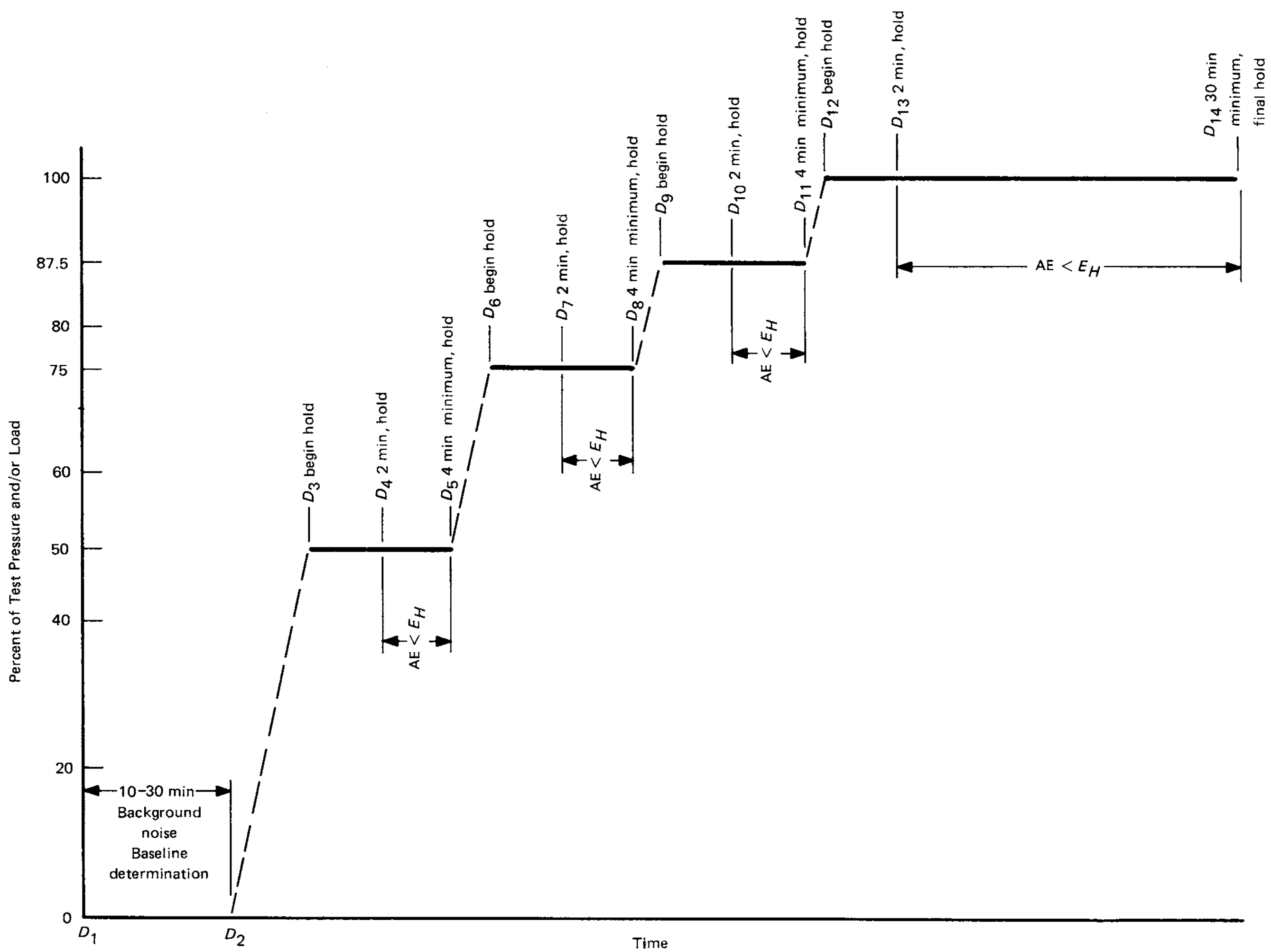
(1) AE events above threshold vs time for zones of interest

(2) total counts vs time, etc.

(3) signal propagation loss

(b) The AE data shall be maintained with the records of the vessel.

Figure T-1173(a)(1)
Atmospheric Vessels Loading Sequence



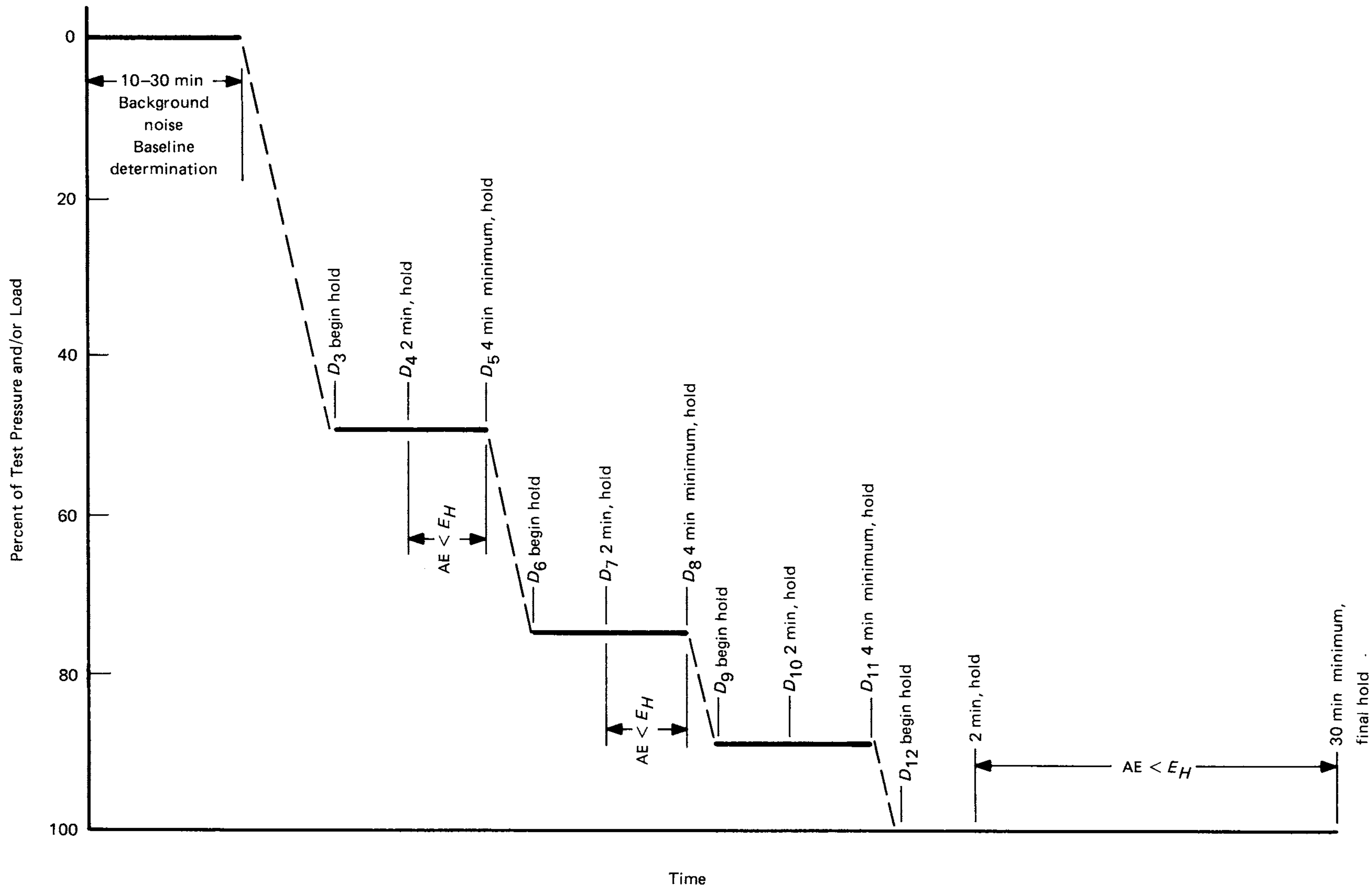
GENERAL NOTES:

(a) For previously filled vessels, see Table T-1121 for level of test stress at start of test.

(b) For evaluation criteria, see Table T-1181.

(c) D_n = data record point.

Figure T-1173(a)(2)
Vacuum Vessels Loading Sequence



GENERAL NOTES:

(a) For evaluation criteria, see Table T-1181.

(b) D_n = data record point.

Figure T-1173(a)(3)
Test Algorithm — Flowchart for Atmospheric Vessels

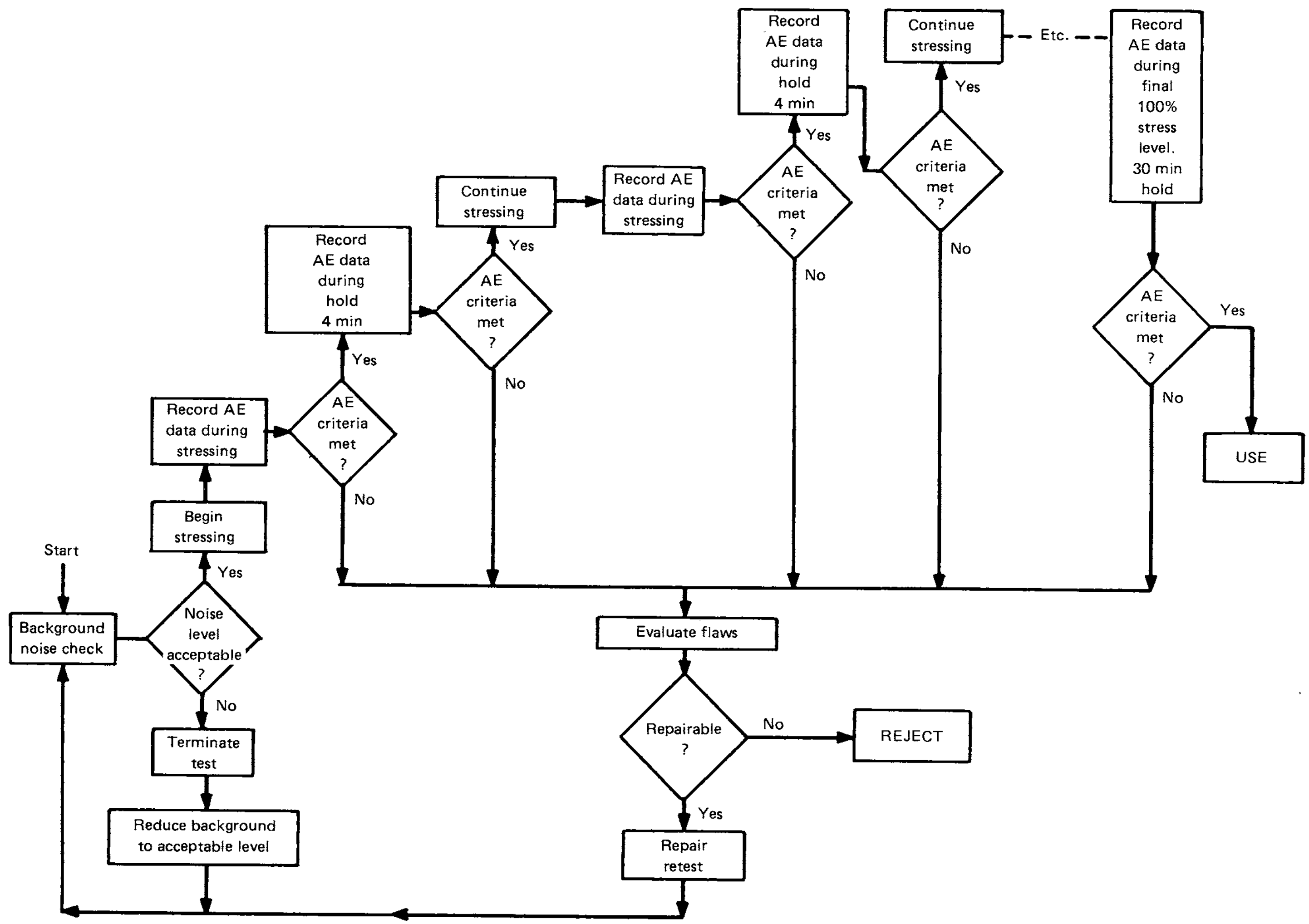
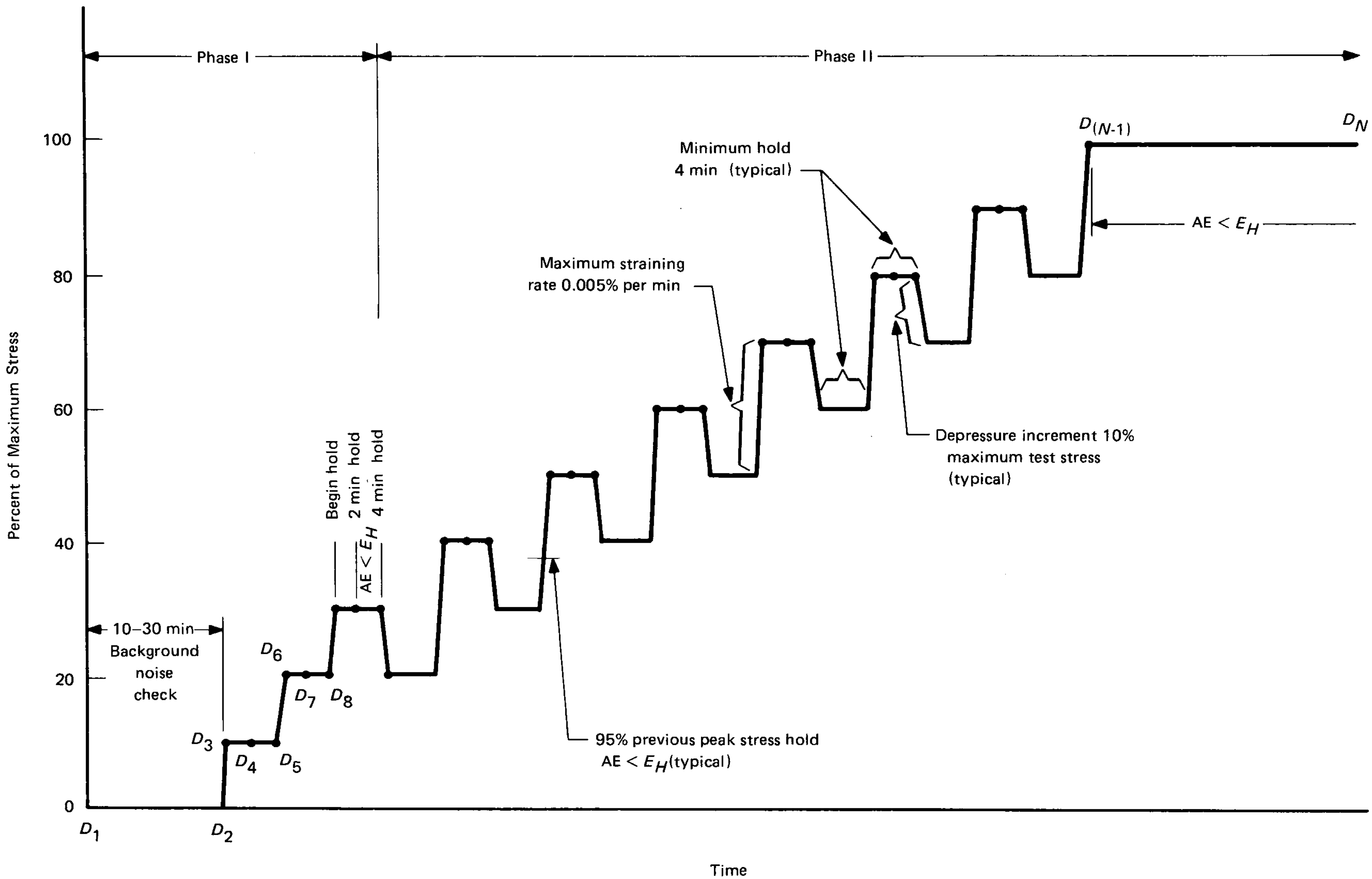


Figure T-1173(b)(1)
Pressure Vessel Loading Sequence



GENERAL NOTES:
(a) For evaluation criteria, see Table T-1181.
(b) D_n = data record point.

Figure T-1173(b)(2)
Algorithm — Flowchart for Pressure Vessels

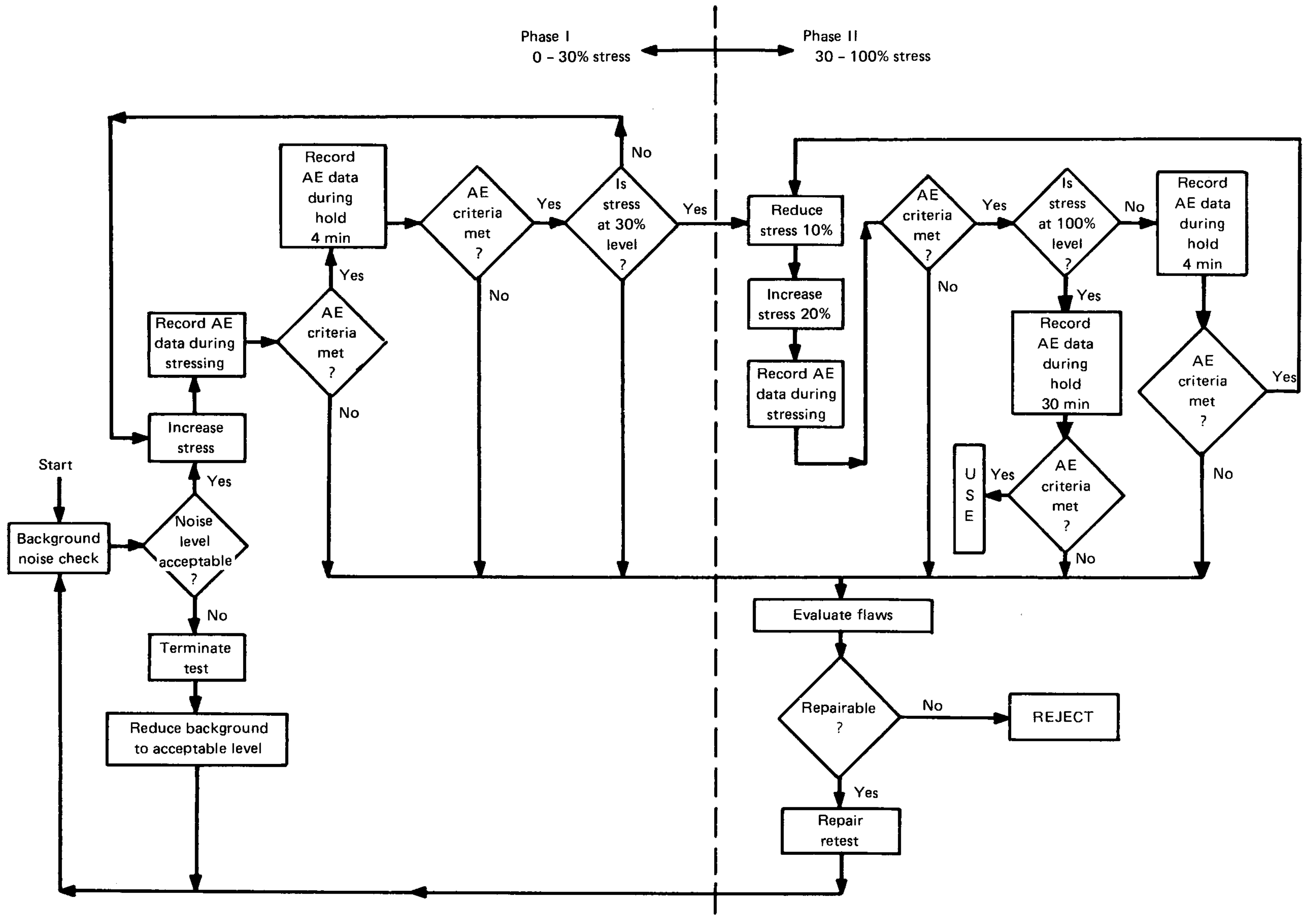


Table T-1181
Evaluation Criteria
Atmospheric (Liquid Head) and Additional Superimposed Pressure

	First Loading	Subsequent Loading	
Emissions during hold	Less than or equal to E_H events beyond time T_H, none having an amplitude greater than A_M [Note (1)]	Less than or equal to E_H events beyond time T_H, none having an amplitude greater than A_M [Note (1)]	Measure of continuing permanent damage [Note (2)]
Felicity ratio	Greater than felicity ratio F_A	Greater than felicity ratio F_A	Measure of severity of previous induced damage
Total [Note (3)]	Not excessive [Note (4)]	Less than N_c total counts	Measure of overall damage during a load cycle
Number of events greater than or equal to reference amplitude threshold	Less than E_{AF} events	Less than E_{AS} events	Measure of high energy microstructure failures. This criterion is often associated with fiber breakage.

GENERAL NOTES:
(a) A_M, E_{AF}, E_{AS}, E_H, F_A, and N_c are acceptance criteria values specified by the referencing Code Section; T_H is specified hold time.
(b) Above temperature.
(c) High-frequency channels shall be used for zone location in an attempt to identify and evaluate emission sources that may represent defects and other indications.

NOTES:
(1) See II-1140 for definition of A_M unless specified by the referencing Code Section.
(2) Permanent damage can include microcracking, debonding, and fiber pull out.
(3) Varies with instrumentation manufacturer; see Mandatory Appendix II for functional definition of N_c. Note that counts criterion N_c may be different for first and subsequent fillings.
(4) Excessive counts are defined as a significant increase in the rate of emissions as a function of load. On a plot of counts against load, excessive counts will show as a departure from linearity.

MANDATORY APPENDIX I
INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1110 AE SENSORS

AE sensors shall be temperature stable over the range of use which may be 40°F to 200°F (5°C to 95°C), and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1111 HIGH FREQUENCY SENSORS

These sensors shall have a resonant response at 100 kHz to 200 kHz. Minimum sensitivity shall be to 80 dB referred to 1 V/μbar, determined by face-to-face ultrasonic calibration. AE sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1112 LOW FREQUENCY SENSORS

These sensors shall have a resonant response between 25 kHz and 75 kHz. Minimum sensitivity shall be comparable to, or greater than, commercially available high sensitivity accelerometers with resonant response in that frequency range. In service, these sensors may be wrapped or covered with a sound-absorbing medium to limit interference by airborne noise, if permitted in the procedure used in making the examination.

I-1120 SIGNAL CABLE

The signal cable from sensor to preamp shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the sensor housing, or a line-driving (matched impedance) sensor is used.

I-1130 COUPLANT

Commercially available couplants for ultrasonic flaw detection accumulated above second threshold may be used (high setting adhesives may also be used, provided couplant sensitivity is not significantly lower than with fluid couplants). Couplant selection should be made to minimize changes in coupling sensitivity during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of attachment are specified in the written procedure.

I-1140 PREAMPLIFIER

The preamplifier, when used, shall be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamp is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Unfiltered frequency response shall not vary more than 3 dB over the frequency range of 25 kHz to 300 kHz, and over the temperature range of 40°F to 125°F (5°C to 50°C). For sensors with integral preamps, frequency response characteristics shall be confined to a range consistent with the operational frequency of the sensor.

I-1150 FILTERS

Filters shall be of the band pass or high pass type, and shall provide a minimum of −24 dB/octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamp, or processor to limit frequency response. Filters and/or integral design characteristics shall insure that the principal processing frequency for high frequency sensors is not less than 100 kHz, and for low frequency sensors not less than 25 kHz.

I-1160 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30 m) of cable length. The recommended maximum cable length is 500 ft (150 m) to avoid excessive signal attenuation. Digital or radio transmission of signals is allowed if consistent with standard practice in transmitting those signal forms.

I-1161 POWER SUPPLY

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1170 MAIN AMPLIFIER

The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range of 25 kHz to 300 kHz, and temperature range of 40°F to 125°F (5°C to 50°C). The written procedure shall specify the use and nomenclature of the main amplifier.

The main amplifier shall have adjustable gain, or an adjustable threshold for event detection and counting.

I-1180 MAIN PROCESSOR

I-1181 GENERAL

The main processor(s) shall have active data processing circuits through which high frequency and low frequency sensor (if used) data will be processed independently. If independent channels are used, the processor shall be capable of processing events and counts on each channel. No more than two sensors may be commoned into a single preamplifier.

If a summer or mixer is used, it shall provide a minimum processing capability for event detection on eight channels (preamp inputs).

Low frequency sensor information will be processed for emission activity. Total counts will be processed from the high frequency sensors only. Events accumulated above second threshold (high amplitude events) will be processed from the high frequency sensors only. The high amplitude signal threshold may be established through signal gain reduction, threshold increase, or peak amplitude detection.

(a) Threshold. The AE instrument used for examination shall have a threshold control accurate to within 2 dB over its useful range.

(b) Counts. The AE instrument used for examination shall detect counts over a set threshold within an accuracy of ±5%.

(c) Events. The AE instrument used for examination shall be capable of continuously measuring 100 events ±1 event/sec, over a set threshold.

(d) Peak Amplitude. When peak amplitude detection is used, the AE instrument used for examination shall measure the peak amplitude within an accuracy of ±2 dB over a set threshold.

(e) M. The AE instrument used for examination shall be capable of measuring an *M* value (if used).

(f) Field Performance Verification. At the beginning of each vessel test the performance of each channel of the AE instrument shall be checked using an electronic waveform generator and a stress wave generator.

(g) Waveform Generator. This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, it shall be able to verify system operation for threshold, counts, and if used, duration, and peak amplitude measurements over the range of 25 kHz to 200 kHz.

(h) Stress Wave Generator. This device shall transmit a stress wave pulse into the sensor. AE instrumentation response shall be within 5 dB of the response of the same sensor model when new.

The AE channel response to a single lead break shall be within 5 dB of the channel response of the same sensor model when new.

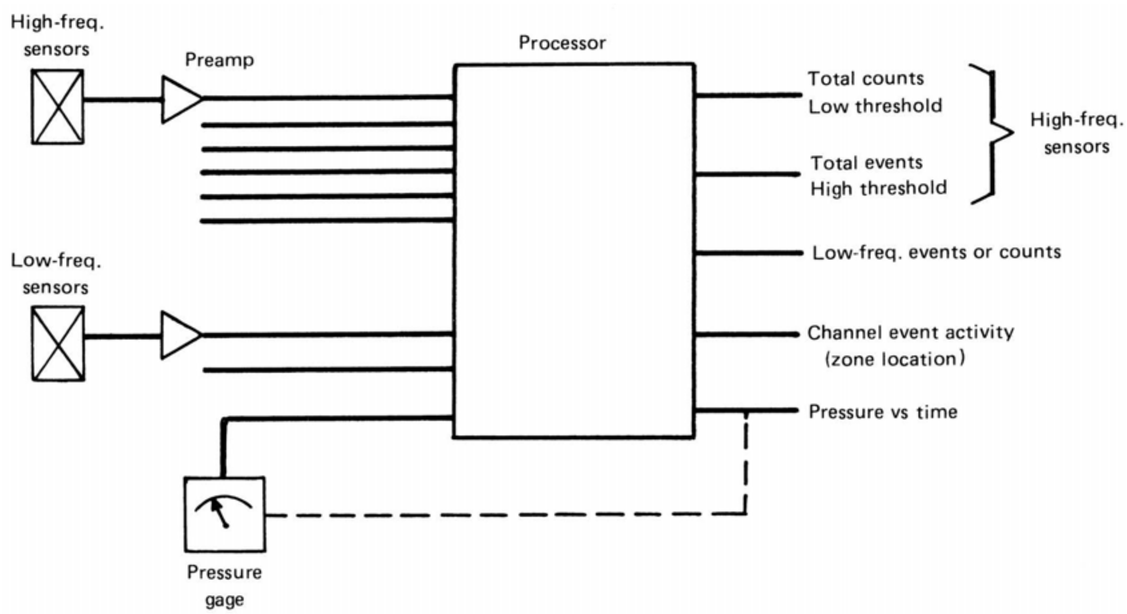
I-1182 PEAK AMPLITUDE DETECTION

If peak amplitude detection is practiced, comparative calibration must be established per the requirements of Mandatory Appendix II. Usable dynamic range shall be a minimum of 60 dB with 2 dB resolution over the frequency band of 100 kHz to 300 kHz, and the temperature range of 40°F to 125°F (5°C to 50°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or dB, but must be referenced to a fixed gain output of the system (sensor or preamp).

I-1183 SIGNAL OUTPUTS AND RECORDING

The processor as a minimum shall provide outputs for permanent recording of total counts for high frequency sensors, events by channel (zone location), and total events above the reference amplitude threshold for high frequency sensors. A sample schematic is shown in Figure I-1183.

Figure I-1183
Sample of Schematic of AE Instrumentation for Vessel Examination



MANDATORY APPENDIX II
INSTRUMENT CALIBRATION

II-1110 GENERAL

The performance and threshold definitions vary for different types of acoustic emission equipment. Parameters such as counts, amplitude, energy, and *M* vary from manufacturer to manufacturer, and from model to model by the same manufacturer. This Appendix defines procedures for determining the threshold of acoustic emission detectability, reference amplitude threshold, and count criterion N_c.

The procedures defined in this Appendix are intended for baseline instrument calibration at 60°F to 80°F (15°C to 25°C). Instrumentation users shall develop calibration techniques traceable to the baseline calibration outlined in this Appendix. For field use, electronic calibrators, small portable samples (acrylic or similar), can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1120 THRESHOLD

Threshold of acoustic emission detectability shall be determined using a 4 ft × 6 ft × $^1/_2$ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The threshold of detectability is defined as the average measured amplitude of ten events generated by 0.3 mm pencil (2H) lead break at a distance of 4 ft 3 in. (1.3 m) from the sensor. A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (150 mm) from the 4 ft (1.2 m) side and mid-distance between the 6 ft (1.8 m) sides.

As an alternative to using the lead sheet, a cast acrylic rod may be used. The use of the acrylic rod for verifying the consistency of acoustic emission sensor response is given in SE-2075. The method for determining the threshold of acoustic emission detectability using the acrylic rod is given in SE-1067, A2.2.

These threshold of AE detectability requirements may be met through measurements performed by the user or the equipment manufacturer.

II-1130 REFERENCE AMPLITUDE THRESHOLD

For large amplitude events, the reference amplitude threshold shall be determined using a 10 ft × 2 in. × $^3/_4$ in. (3.0 m × 50 mm × 19 mm) clean, mild steel bar. The bar shall be supported at each end by elastomeric, or similar, isolating pads. The reference amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor (see II-1120). A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 12 in. (300 mm) from the end of the bar on the 2 in. (50 mm) wide surface. These requirements may be performed by the user or equipment manufacturer.

II-1140 COUNT CRITERION N_C AND A_M VALUE

The count criterion N_c shall be determined either before or after the test using a 0.3 mm pencil (2H) lead broken on the surface of the vessel. A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. Calibration points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid line (if applicable), and away from manways, nozzles, etc.

Two calibrations shall be carried out for each calibration point. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45 deg to the direction of the first calibration. Breaks shall be at a distance from the calibration point so as to provide an amplitude decibel value A_M midway between the threshold of detectability (see II-1120) and reference amplitude threshold (see II-1130).

The count criterion N_c shall be based on the counts recorded from a defined (referencing Code Section) number of 0.3 mm pencil (2H) lead breaks at each of the two calibration points.

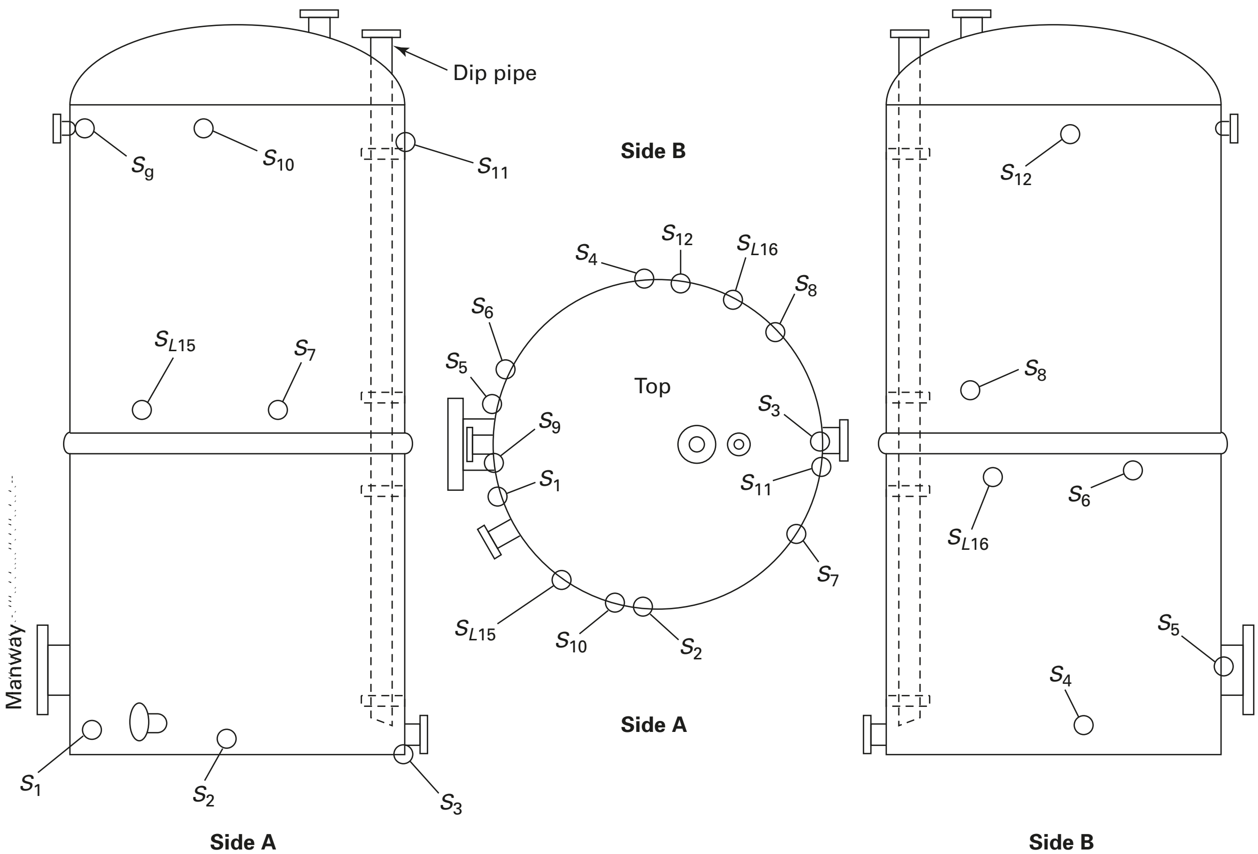
When applying the count criterion, the count criterion value, which is representative of the region where activity is observed, should be used.

II-1160 FIELD PERFORMANCE

As installed on the vessel, no channel shall deviate by more than 6 dB from the average peak response of all channels when lead breaks, or other simulated transient sources, are introduced 6 in. (150 mm) from the sensor.

NONMANDATORY APPENDIX A
SENSOR PLACEMENT GUIDELINES

Figure A-1110
Case 1 — Atmospheric Vertical Vessel



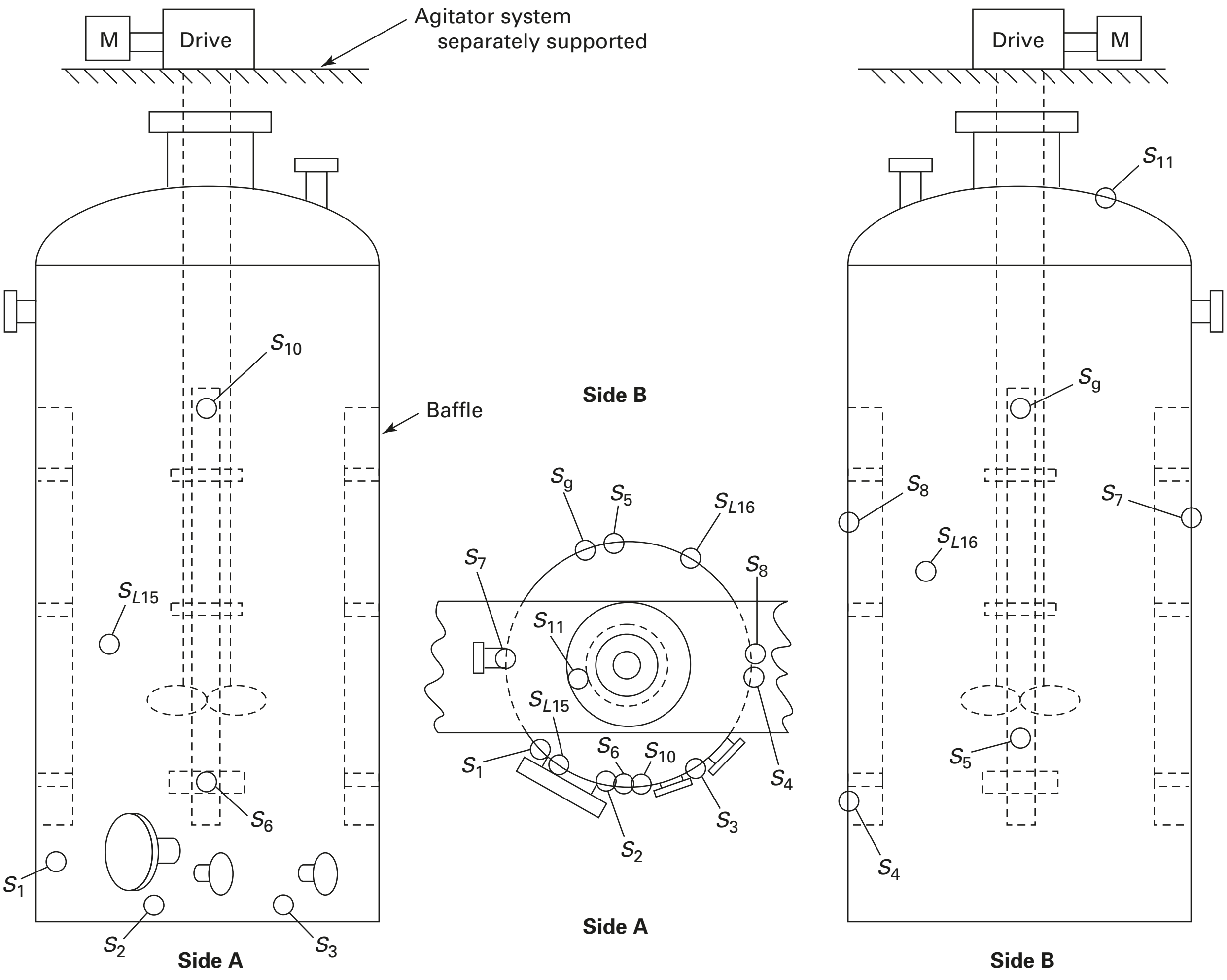
GUIDELINES:

(1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from knuckle on shell.

(2) The secondary bond joint areas are suspect, e.g., nozzles, manways, shell butt joint, etc. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from intersection with shell and below. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart — one above and one below the joint.

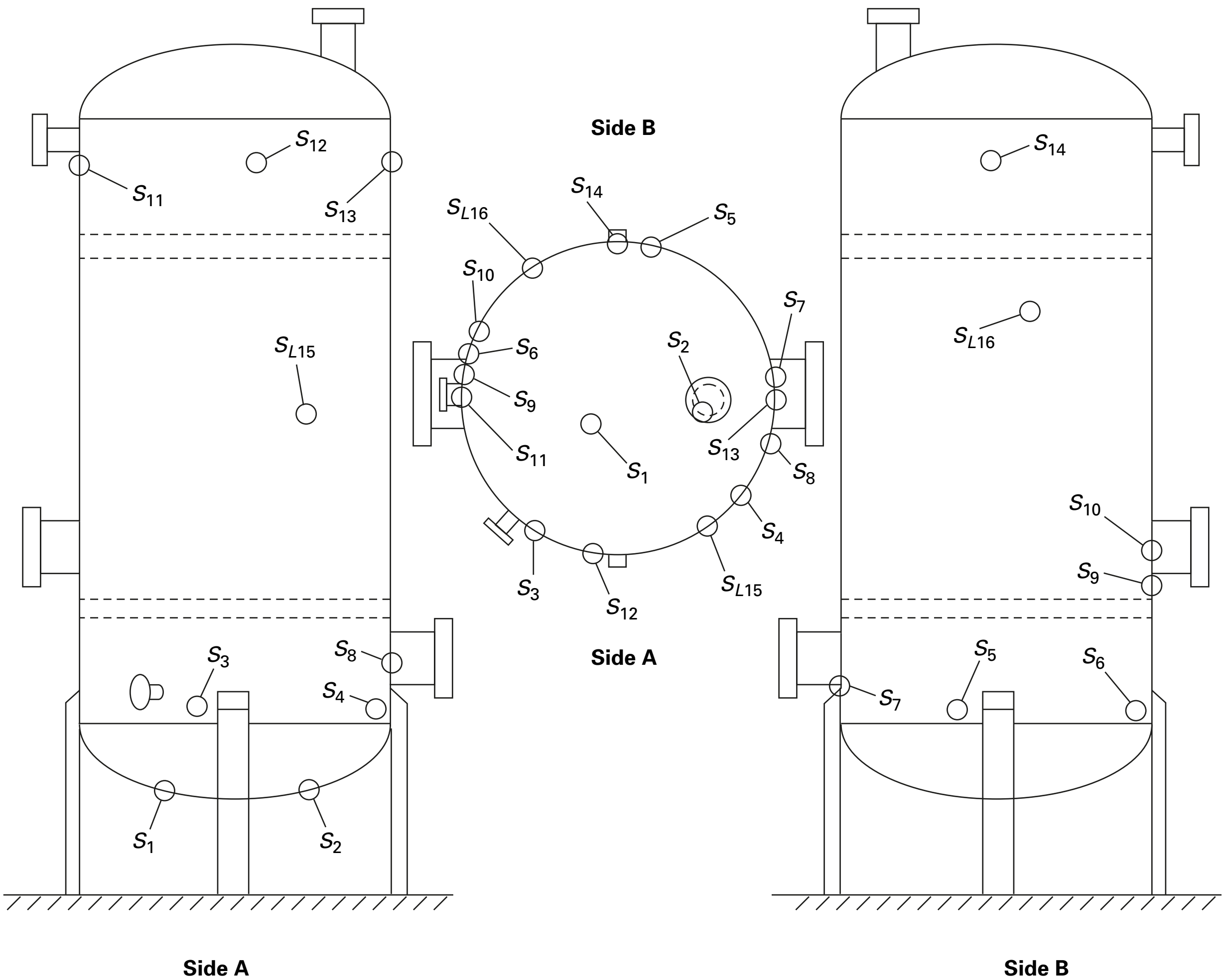
(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height — one above and one below the joint. Space as far apart as possible — up to 180 deg. and at 90 deg. to the high frequency pair.

Figure A-1120
Case 2 — Atmospheric Vertical Vessel



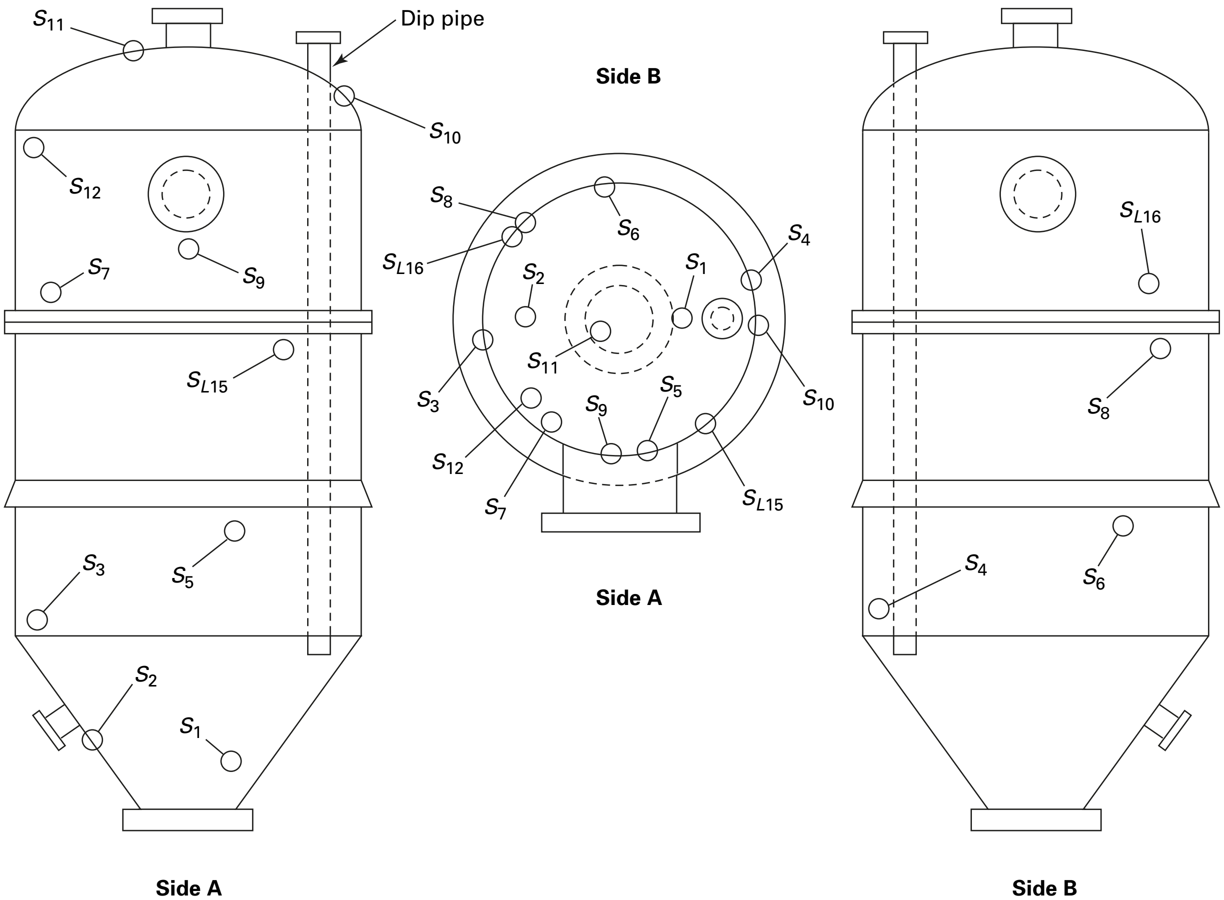
GUIDELINES:
(1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from the knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle areas plus the knuckle regions are covered.
(2) The secondary bond joint areas are suspect, e.g., nozzles, manways, and baffle attachments to shell. See the last sentence of above for bottom region coverage in this example. Note sensor adjacent to agitator shaft top manway. This region should be checked with agitator on.
(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height, one above and one below joint. They should be spaced as far apart as possible — up to 180 deg.

Figure A-1130
Case 3 — Atmospheric/Pressure Vessel



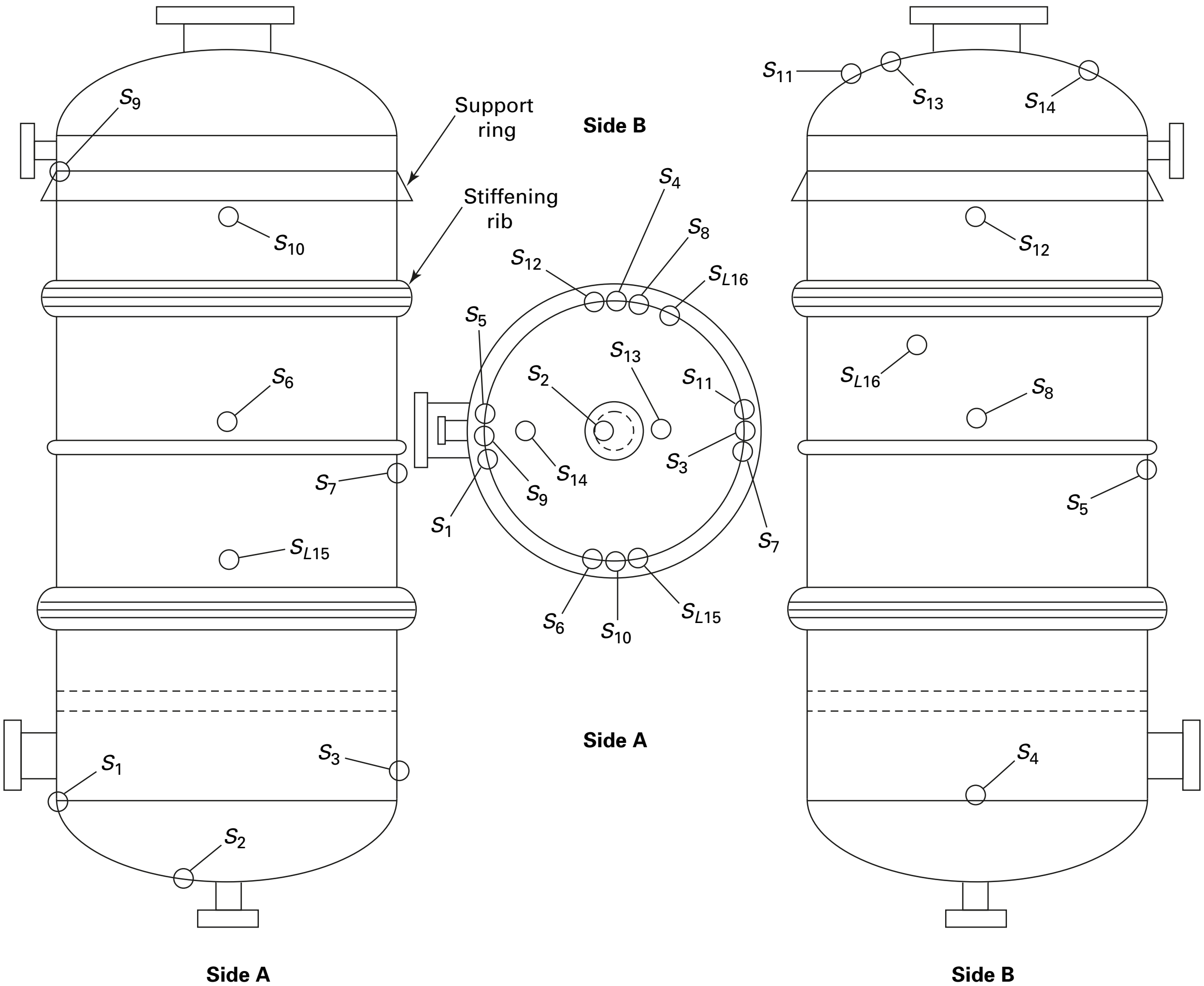
GUIDELINES:
(1) The bottom head is highly stressed. Locate two sensors approximately as shown.
(2) The bottom knuckle region is critical. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from knuckle on shell. The top knuckle region is similarly treated.
(3) The secondary bond areas are suspect, i.e., nozzles, manways, and leg attachments. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from the intersection with shell and below. For leg attachments, there should be a sensor within 12 in. (300 mm) of the shell-leg interface.
(4) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height — one above and one below joint. They should be spaced as far apart as possible up to 180 deg.

Figure A-1140
Case 4 — Atmospheric/Pressure Vertical Vessel



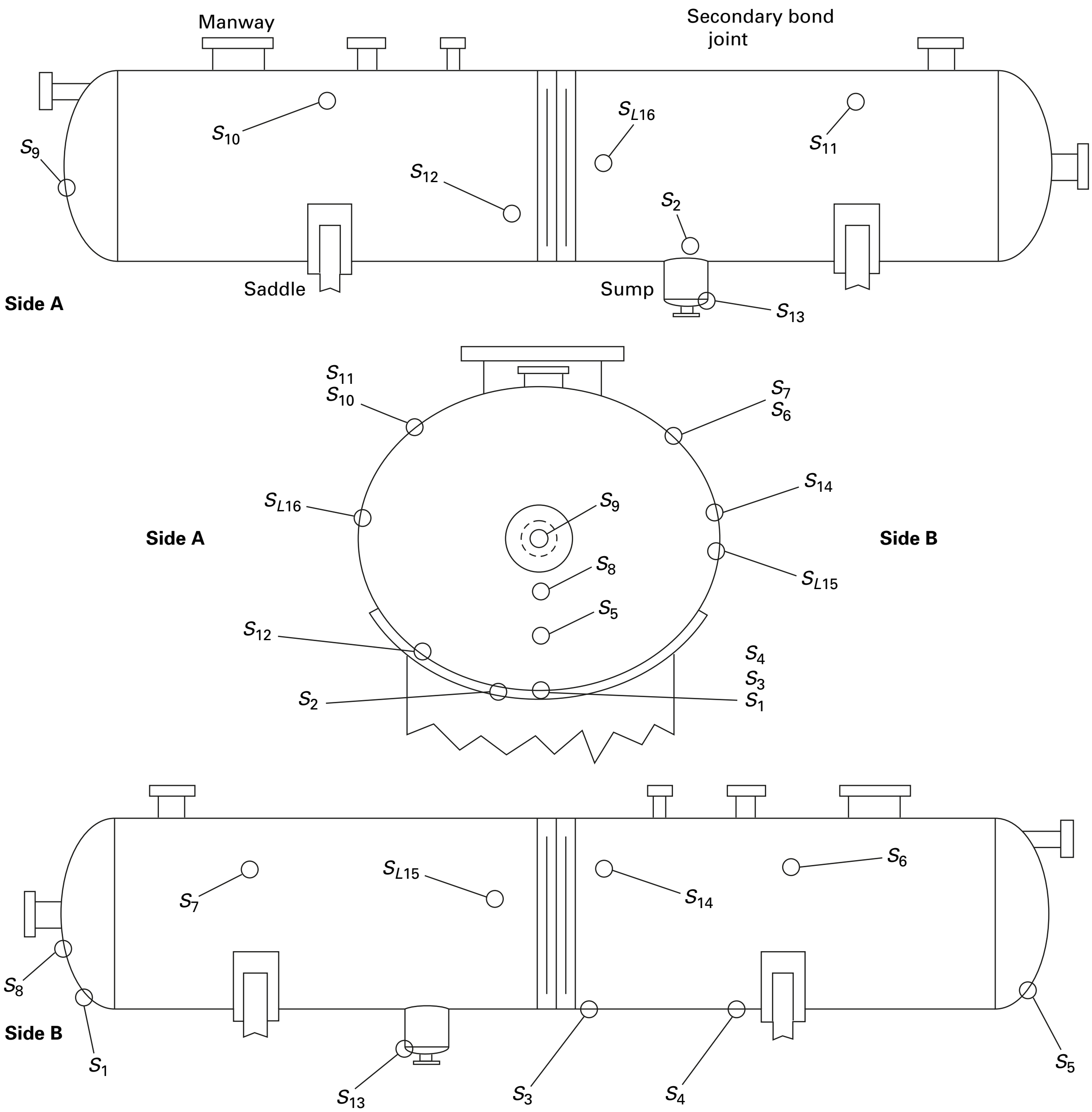
GUIDELINES:
(1) The secondary bond joint areas are suspect, i.e., nozzles, manways, and body flanges. Particularly critical in this vessel are the bottom manway and nozzle. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from intersection with shell and below. The bottom flange in this example is covered by sensor 3 in. to 6 in. (75 mm to 150 mm) above the manway. The body flange is covered by low frequency sensors S_{L15} and S_{L16} — one above and one below the body flange and spaced as far apart as possible — up to 180 deg. Displaced approximately 90 deg. from this pair and spaced up to 180 deg. apart are the two high frequency sensors — one above and one below the flange.
(2) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 3 in. to 6 in. (75 mm to 150 mm) away from knuckle on shell.

Figure A-1150
Case 5 — Atmospheric/Vacuum Vertical Vessel



GUIDELINES:
(1) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from knuckle on shell.
(2) The secondary bond joint areas are critical, e.g., nozzles, manways, and shell butt joints. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from the intersection with the shell (or head) and below, where possible. The shell butt joint region is important. Locate sensors up to 180 deg. apart where possible and alternately above and below joint.
(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height — one above and one below the joint. They should be spaced as far apart as possible — up to 180 deg. and at 90 deg. to other pair.

Figure A-1160
Case 6 — Atmospheric/Pressure Horizontal Tank



GUIDELINES:

(1) The discontinuity stresses at the intersection of the heads and the shell in the bottom region are important. Sensors should be located to detect structural problems in these areas.

(2) The secondary bond joint areas are suspect, e.g., shell butt joint, nozzles, manways, and sump. The preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from intersecting surfaces of revolution. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart — one on either side of the joint.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located in the middle of the tank — one on either side of the joint. They should be spaced as far apart as possible, i.e., up to 180 deg. and at 90 deg. to high frequency pair.

ARTICLE 12
ACOUSTIC EMISSION EXAMINATION OF METALLIC VESSELS DURING PRESSURE TESTING

T-1210 SCOPE

This Article describes methods for conducting acoustic emission (AE) examination of metallic pressure vessels during acceptance pressure testing when specified by a referencing Code Section. When AE examination in accordance with this Article is specified, the referencing Code Section shall be consulted for the following specific requirements:

(a) personnel qualification/certification requirements

(b) requirements/extent of examination and/or volume(s) to be examined

(c) acceptance/evaluation criteria

(d) standard report requirements

(e) content of records and record retention

When this Article is specified by a referencing Code Section, the AE method described in the Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Article 1, Mandatory Appendix I, I-121.8, AE — Acoustic Emission.

(19) T-1220 GENERAL

(a) The principal objectives of AE examination are to detect, locate, and assess emission sources caused by surface and internal discontinuities in the vessel wall, welds, and fabricated parts and components.

(b) All relevant indications caused by AE sources shall be evaluated by other methods of nondestructive examination.

T-1221 VESSEL STRESSING

Arrangements shall be made to stress the vessel using internal pressure as specified by the referencing Code Section. The rate of application of pressure shall be specified in the examination procedure and the pressurizing rate shall be sufficient to expedite the examination with minimum extraneous noise. Provisions shall be made for holding the pressure at designated hold points.

For in-service vessels, the vessel pressure history shall be known prior to the test.

T-1222 NOISE REDUCTION

External noise sources such as rain, foreign objects contacting the vessel, and pressurizing equipment noise must be below the system examination threshold.

T-1223 SENSORS

T-1223.1 Sensor Frequency. Selection of sensor frequency shall be based on consideration of background noise, acoustic attenuation, and vessel configuration. Frequencies in the range of 100 kHz to 400 kHz have been shown to be effective. (See Nonmandatory Appendix B.)

T-1223.2 Sensor Mounting. The location and spacing of the sensors are referenced in T-1264 and T-1265. The sensors shall be acoustically coupled using couplant specified in the written procedure. Suitable couplants include adhesive systems whose bonding and acoustic coupling effectiveness have been demonstrated.

When examining austenitic stainless steels, titanium, or nickel alloys, the need to restrict chloride/fluoride ion content, total chlorine/fluorine content, and sulfur content in the couplant or other materials used on the vessel surface shall be considered and limits agreed upon between contracting parties.

The sensor shall be held in place utilizing methods of attachment, as specified in the written procedure.

The signal cable and preamplifier shall be supported such that the sensor does not move during testing.

T-1223.3 Surface Contact. Sensors shall be mounted directly on the vessel surface, or on integral waveguides.

T-1224 LOCATION OF ACOUSTIC EMISSION SOURCES (19)

(a) Sources shall be located to the specified accuracy by multichannel source location, zone location, or both, as required by the referencing Code Section. All hits detected by the instrument shall be recorded for interpretation and evaluation.

(b) Multichannel source location accuracy shall be within a maximum of 2 component wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

A drawing showing actual sensor locations with dimensions shall be provided and form part of the report.

T-1225 PROCEDURE REQUIREMENTS

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material and configurations to be examined, including dimensions and product form;

(b) background noise measurements;

(c) sensor type, frequency, and Manufacturer;

(d) method of sensor attachment

(e) couplant;

(f) acoustic emission instrument type and filter frequency;

(g) sensor locations;

(h) method for selection of sensor locations;

(i) description of system calibration(s);

(j) data to be recorded and method of recording;

(k) post-examination vessel cleaning;

(l) report requirements; and

(m) qualification/certification of the examiner(s).

T-1230 EQUIPMENT

(a) The AE system consists of sensors, signal processing, display, and recording equipment (see Mandatory Appendix I).

(b) Data measurement and recording instrumentation shall be capable of measuring the following parameters from each AE hit on each channel: counts above system examination threshold, peak amplitude, arrival time, rise time, duration, and Measured Area of the Rectified Signal Envelope (MARSE, which is a measure of signal strength or energy). Mixing or otherwise combining the acoustic emission signals of different sensors in a common preamplifier is not permitted except to overcome the effects of local shielding. (See Article 12, Nonmandatory Appendix B.) The data acquisition system shall have sufficient channels to provide the sensor coverage defined in T-1265. Amplitude distribution, by channel, is required for source characterization. The instrumentation shall be capable of recording the measured acoustic emission data by hit and channel number. Waveform collection in support of source location and characterization may also be required.

(c) Time and pressure shall be measured and recorded as part of the AE data. The pressure shall be continuously monitored to an accuracy of ±2% of the maximum test pressure.

(1) Analog type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(2) Digital type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

T-1260 CALIBRATION

T-1261 SYSTEM CALIBRATION

(See Mandatory Appendix II.)

T-1262 ON-SITE SYSTEM CALIBRATION

Prior to each vessel test or series of tests, the performance of each utilized channel of the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input.

A series of tests is that group of tests using the same examination system which is conducted at the same site within a period not exceeding 8 hr or the test duration, whichever is greater.

This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, on-site system calibration shall be able to verify system operation for threshold, counts, duration, rise time, MARSE (signal strength or energy), and peak amplitude. Calibration values shall be within the range of values specified in Mandatory Appendix I.

T-1263 ATTENUATION CHARACTERIZATION

An attenuation study is performed in order to determine sensor spacing. This study is performed with the test fluid in the vessel using a simulated AE source. For production line testing of identical vessels see Article 12, Nonmandatory Appendix B.

The typical signal propagation losses shall be determined according to the following procedure: select a representative region of the vessel away from manways, nozzles, etc., mount a sensor, and strike a line out from the sensor at a distance of 10 ft (3 m) if possible. Break 0.3 mm (2H) leads next to the sensor and then again at 1 ft (0.3 m) intervals along this line. The breaks shall be done with the lead at an angle of approximately 30 deg to the surface and with a 0.1 in. (2.5 mm) lead extension.

T-1264 SENSOR LOCATION

Sensor locations on the vessel shall be determined by the vessel configuration and the maximum sensor spacing (see T-1265). A further consideration in locating sensors is the need to detect structural flaws at critical sections, e.g., welds, high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Additional consideration should be given to the possible attenuation effects of welds. See Article 12, Nonmandatory Appendix B. Sensor location guidelines for zone location for typical vessel types are given in Nonmandatory Appendix A.

T-1265 SENSOR SPACING

T-1265.1 Sensor Spacing for Zone Location. Sensors shall be located such that a lead break at any location in the examination area is detected by at least one sensor and have a measured amplitude not less than as specified by the referencing Code Section. The maximum sensor spacing shall be no greater than $1\frac{1}{2}$ times the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel has a measured amplitude value equal to the evaluation threshold.

T-1265.2 Sensor Spacing for Multichannel Source Location Algorithms. Sensors shall be located such that a lead break at any location in the examination area is detected by at least the minimum number of sensors required for the algorithms.

T-1266 SYSTEMS PERFORMANCE CHECK

A verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again immediately following the test. The peak amplitude response of each sensor to a repeatable simulated acoustic emission source at a specific distance from each sensor should be taken prior to and after the test. The measured peak amplitude should not vary more than 4 dB from the average of all the sensors. Any channel failing this check should be investigated and replaced or repaired as necessary. If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid system performance check shall be reexamined.

Sensor performance and response may also be checked using electronic automatic sensor calibration programs if the system being used is able to also check sensor coupling and permanently record the results. This shall be done at the start of the test and at the completion of the test.

T-1270 EXAMINATION

T-1271 GENERAL GUIDELINES

The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

If the vessel has been in service, maximum stress levels shall exceed the previous highest stress level the vessel has seen by a minimum of 5% but shall not exceed the vessel's maximum design pressure.

T-1272 BACKGROUND NOISE

Extraneous noise must be identified, minimized, and recorded.

T-1272.1 Background Noise Check Prior to Loading. Acoustic emission monitoring of the vessel during intended examination conditions is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 15 min. If background noise is above the evaluation threshold, the source of the noise shall be eliminated or the examination terminated.

T-1272.2 Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include:

(a) liquid splashing into a vessel;
(b) a pressurizing rate that is too high;
(c) pumps, motors, and other mechanical devices;
(d) electromagnetic interference; and
(e) environment (rain, wind, etc.).

Leaks from the vessel such as valves, flanges, and safety relief devices can mask AE signals from the structure. Leaks must be eliminated prior to continuing the examination.

T-1273 VESSEL PRESSURIZATION

T-1273.1 General Guidelines. Rates of pressurization, pressurizing medium, and safety release devices shall be as specified by the referencing Code Section. The pressurization should be done at a rate that will expedite the test with a minimum of extraneous noise. (19)

T-1273.2 Pressurization Sequence.

T-1273.2.1 Pressurization Sequence for New Vessels. The examination shall be done in accordance with the referencing Code Section. Pressure increments shall generally be to 50%, 65%, 85%, and 100% of maximum test pressure. Hold periods for each increment shall be 10 min and for the final hold period shall be at least 30 min. (See Figure T-1273.2.1.) Normally, the pressure test will cause local yielding in regions of high secondary stress. Such local yielding is accompanied by acoustic emission which does not necessarily indicate discontinuities. Because of this, only large amplitude hits and hold period data are considered during the first loading of vessels without postweld heat treatment (stress relief). If the first loading data indicates a possible discontinuity or is inconclusive, the vessel shall be repressurized from 50% to at least 98% of the test pressure with intermediate load holds at 50%, 65%, and 85%. Hold periods for the second pressurization shall be the same as for the original pressurization.

T-1273.2.2 Pressurization Sequence for In-Service Vessels. The examination shall be done in accordance with the referencing Code Section. Load (where load is the combined effect of pressure and temperature) increments shall generally be to 90%, 100%, 105%, and (if possible) 110% of the maximum operating load. Hold periods for each increment shall be 10 min and for the final hold period shall be at least 30 min. (See Figure T-1273.2.2.) The maximum test load shall not be less than 105% of the maximum operating value during the past 6 months of operation or since the last test, whichever is less. Loading rates shall not exceed 10% of the maximum test load over 2 min.

T-1273.3 Test Termination. Departure from a linear count or MARSE vs. load relationship should signal caution. If the AE count or MARSE rate increases rapidly with load, the vessel shall be unloaded and either the test terminated or the source of the emission determined and the safety of continued testing evaluated. A rapidly (exponentially) increasing count or MARSE rate may indicate uncontrolled, continuing damage indicative of impending failure.

T-1280 EVALUATION

T-1281 EVALUATION CRITERIA

The AE criteria shown in Table T-1281 are set forth as one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria to be used shall be as specified in the referencing Code Section.

T-1290 DOCUMENTATION

T-1291 WRITTEN REPORT

The report shall include the following:

(a) complete identification of the vessel, including material type, method of fabrication, Manufacturer's name, and certificate number;

(b) vessel sketch of Manufacturer's drawing with dimensions and sensor locations;

(c) test medium employed;

(d) test medium temperature;

(e) test sequence load rate, hold times, and hold levels;

(f) attenuation characterization and results;

(g) record of system performance verifications;

(h) correlation of test data with the acceptance criteria;

(i) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;

(j) any unusual effects or observations during or prior to the test;

(k) date(s) of test(s);

(l) name(s) and qualifications of the test operator(s); and

(m) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, instrument settings, calibration data, etc.

T-1292 RECORD

(a) A permanent record AE data includes

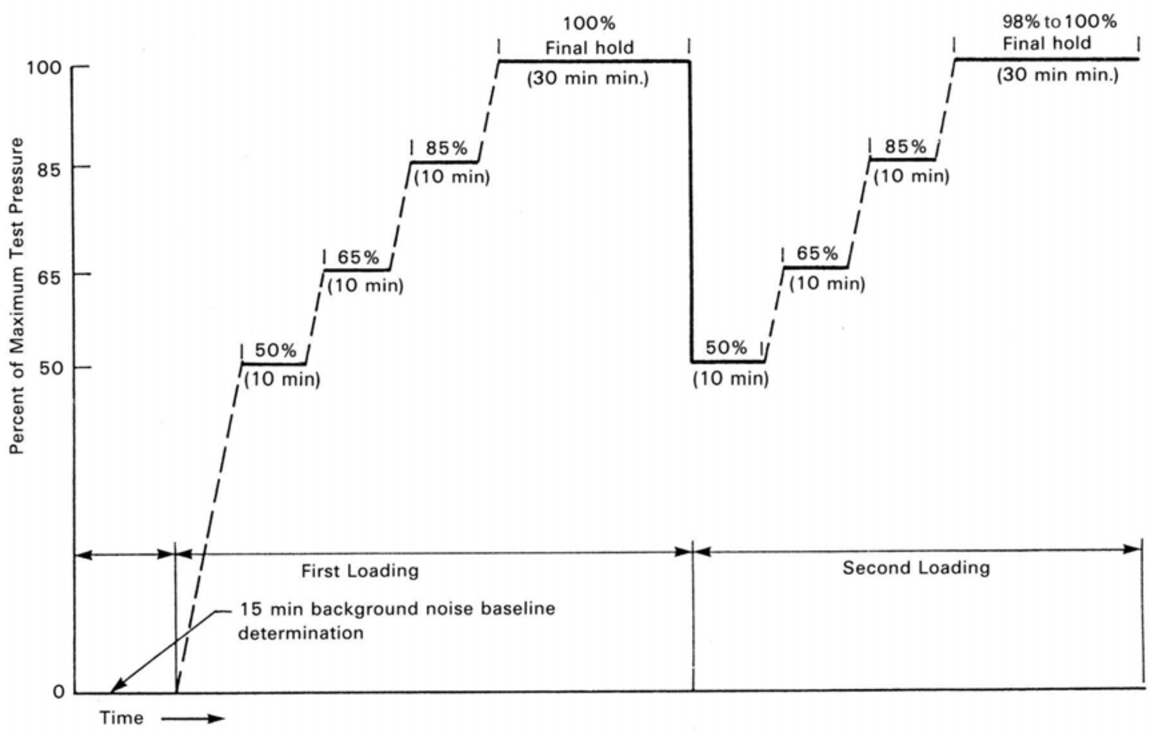
(1) AE hits above threshold vs time and/or pressure for zones of interest

(2) total counts or MARSE (signal strength or energy) vs time and/or pressure, and

(3) written reports

(b) The AE data shall be maintained with the records of the vessel.

Figure T-1273.2.1
An Example of Pressure Vessel Test Stressing Sequence



GENERAL NOTE: During loading, increases in pressure/load levels should not exceed 10% of the maximum test pressure in 2 min.

Figure T-1273.2.2
An Example of In-Service, Pressure Vessel, Test Loading Sequence

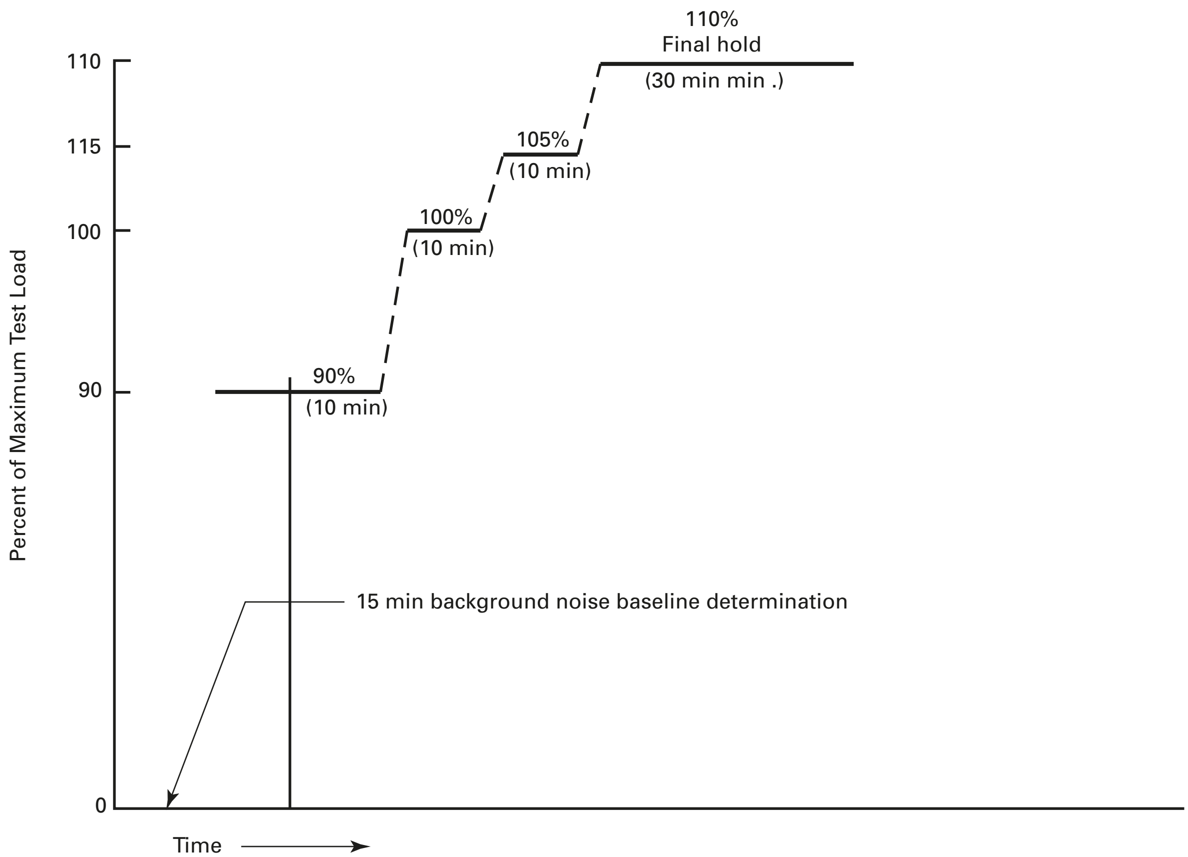


Table T-1281
An Example of Evaluation Criteria for Zone Location

	Emission During Load Hold	Count Rate	Number of Hits	Large Amplitude Hits	MARSE or Amplitude	Activity	Evaluation Threshold, dB
(First Loading) Pressure vessels without full postweld heat treatment	Not more than E_H hits beyond time T_H	Not applied	Not applied	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load	Activity does not increase with increasing load	V_{TH}
Pressure vessels other than those covered above	Not more than E_H hits beyond time T_H	Less than N_T counts per sensor for a specified load increase	Not more than E_T hits above a specified amplitude	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load	Activity does not increase with increasing load	V_{TH}

GENERAL NOTES:
(a) E_H, N_T, and E_A are specified acceptance criteria values specified by the referencing Code Section.
(b) V_{TH} is the specified evaluation threshold.
(c) T_H is the specified hold time.

MANDATORY APPENDIX I
INSTRUMENTATION PERFORMANCE REQUIREMENTS

(19) I-1210 ACOUSTIC EMISSION SENSORS

I-1211 GENERAL

Acoustic emission sensors in the range of 100 kHz to 400 kHz shall be temperature-stable over the range of intended use, and shall not exhibit sensitivity changes greater than 3 dB over this range as guaranteed by the Manufacturer. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1212 SENSOR CHARACTERISTICS

Sensors shall have a resonant response between 100 kHz – 400 kHz. Minimum sensitivity shall be −80 dB referred to 1 V/μbar, determined by face-to-face ultrasonic test.

NOTE: This method measures relative sensitivity of the sensor. Acoustic emission sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1220 SIGNAL CABLE

The signal cable from sensor to preamplifier shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference.

I-1230 COUPLANT

Couplant selection shall provide consistent coupling efficiency during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of sensor attachment shall be specified in the written procedure.

I-1240 PREAMPLIFIER

The preamplifier shall be mounted in the vicinity of the sensor, or in the sensor housing. If the preamplifier is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Frequency response shall not vary more than 3 dB over the operating frequency and temperature range of the sensors.

I-1250 FILTER

Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB/octave signal attenuation. Filters shall be located in preamplifier. Additional filters shall be incorporated into the processor. Filters shall insure that the principal processing frequency corresponds to the specified sensor frequency.

I-1260 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30 m) of cable length. The recommended maximum cable length is 500 ft (150 m) to avoid excessive signal attenuation.

I-1270 POWER SUPPLY

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1280 MAIN AMPLIFIER

The gain in the main amplifier shall be linear within 3 dB over the temperature range of 40°F to 125°F (5°C to 50°C).

I-1290 MAIN PROCESSOR

I-1291 GENERAL

The main processor(s) shall have processing circuits through which sensor data will be processed. It shall be capable of processing hits, counts, peak amplitudes, duration, rise time, waveforms, and MARSE (signal strength or energy) on each channel.

(a) Threshold. The AE instrument used for examination shall have a threshold control accurate to within 1 dB over its useful range.

(b) Counts. The AE counter circuit used for examination shall detect counts over a set threshold within an accuracy of ±5%.

(c) Hits. The AE instrument used for examination shall be capable of measuring, recording, and displaying a minimum of 40 hits/sec total for all channels for a minimum period of 10 sec and continuously measuring,

recording, and displaying a minimum of 40 hits/sec total for all channels. The system shall display a warning if there is greater than a 5 sec lag between recording and display during high data rates.

(d) Peak Amplitude. The AE circuit used for examination shall measure the peak amplitude with an accuracy of ±2 dB.

(e) Energy. The AE circuit used for examination shall measure MARSE (signal strength or energy) with an accuracy of ±5%. The usable dynamic range for energy shall be a minimum of 40 dB.

(f) Parametric Voltage. If parametric voltage is measured by the AE instrument, it should measure to an accuracy of 2% of full scale.

I-1292 PEAK AMPLITUDE DETECTION

Comparative calibration must be established per the requirements of Mandatory Appendix II. Usable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency band width of 100 kHz to 400 kHz, and the temperature range of 40°F to 125°F (5°C to 50°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be stated in dB, and must be referenced to a fixed gain output of the system (sensor or preamplifier).

MANDATORY APPENDIX II
INSTRUMENT CALIBRATION AND CROSS-REFERENCING

II-1210 MANUFACTURER'S CALIBRATION

Acoustic emission system components will be provided from the Manufacturer with certification of performance specifications and tolerances.

II-1211 ANNUAL CALIBRATION

The instrument shall have an annual comprehensive calibration following the guidelines provided by the Manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1220 INSTRUMENT CROSS-REFERENCING

The performance and threshold definitions vary for different types of AE instrumentation. Parameters such as counts, amplitude, energy, etc., vary from Manufacturer to Manufacturer and from model to model by the same Manufacturer. This section of appendix describes techniques for generating common baseline levels for the different types of instrumentation.

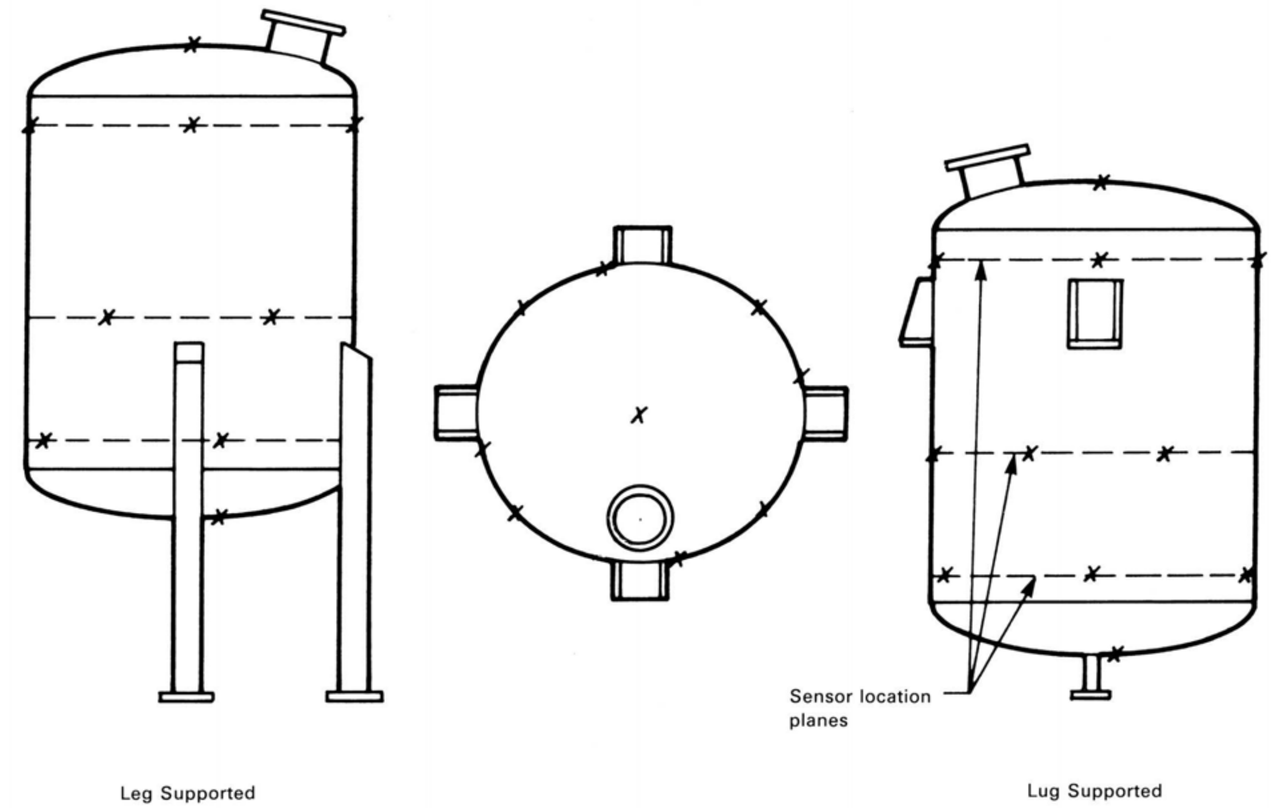
The procedures are intended for baseline instrument calibration at 60°F to 80°F (16°C to 27°C). For field use, small portable signal generators and calibration transducers can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1221 SENSOR CHARACTERIZATION

Threshold of acoustic emission detectability is an amplitude value. All sensors shall be furnished with documented performance data. Such data shall be traceable to NBS standards. A technique for measuring threshold of detectability is described in Article 11, Mandatory Appendix II.

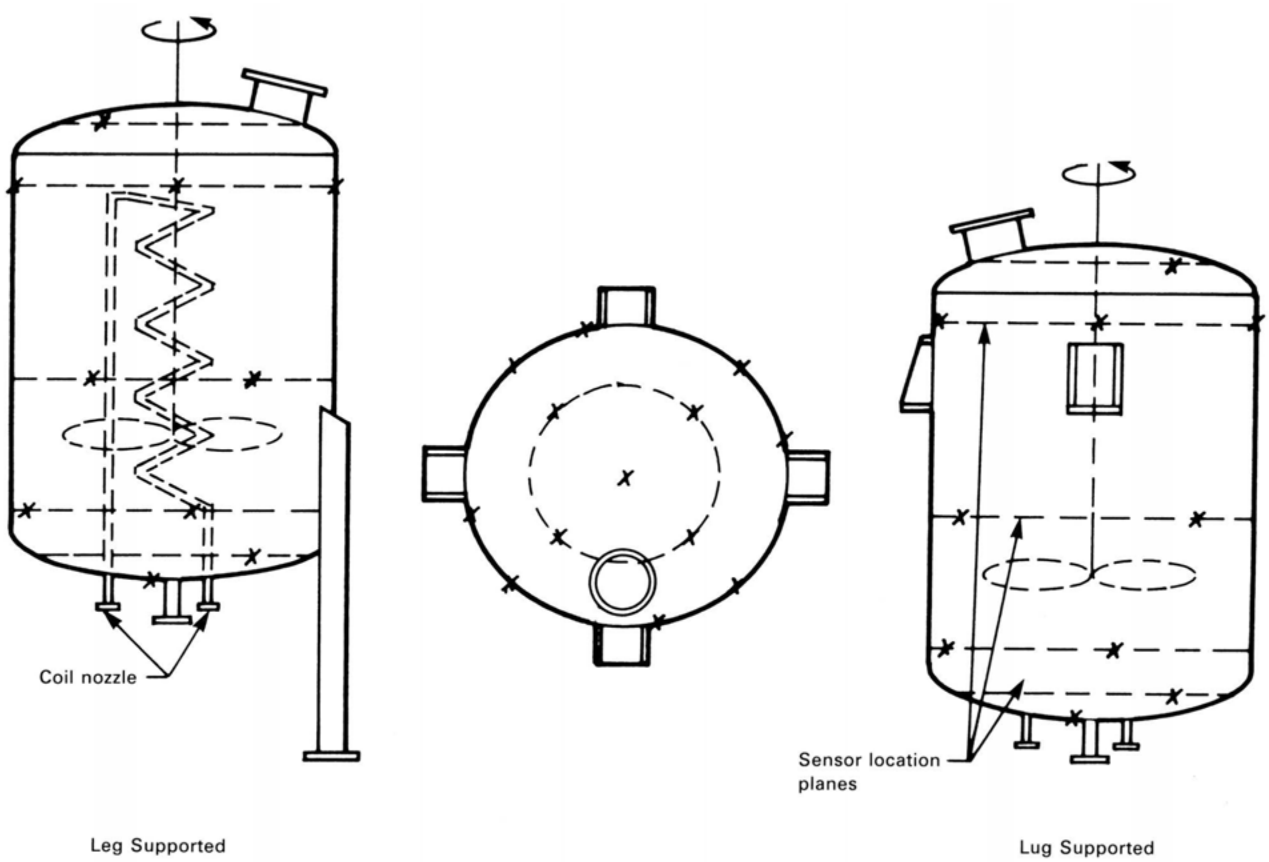
NONMANDATORY APPENDIX A
SENSOR PLACEMENT GUIDELINES

Figure A-1210
Case 1 — Vertical Pressure Vessel Dished Heads, Lug or Leg Supported



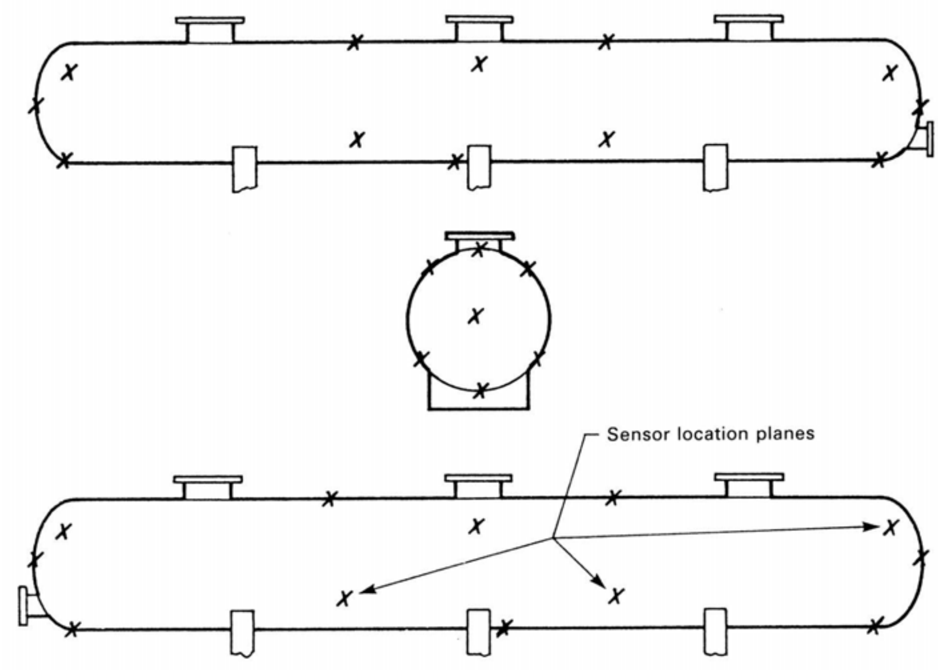
GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional rows of sensors may be required.

Figure A-1220
Case 2 — Vertical Pressure Vessel Dished Heads, Agitated, Baffled Lug, or Leg Support



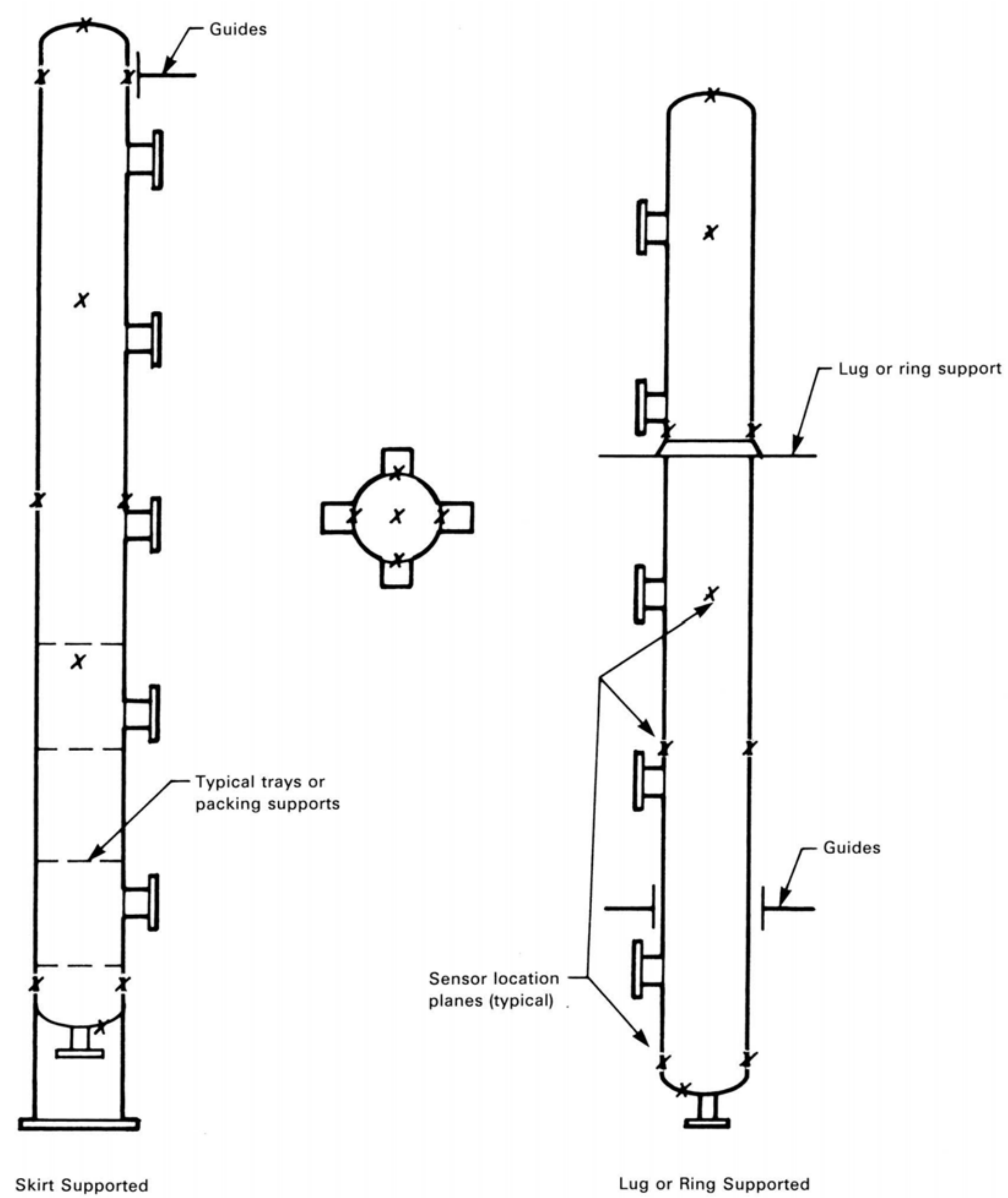
GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Sensors may be located on outlet to detect defects in coil.
(3) Additional rows of sensors may be required.

Figure A-1230
Case 3 — Horizontal Pressure Vessel Dished Heads, Saddle Supported



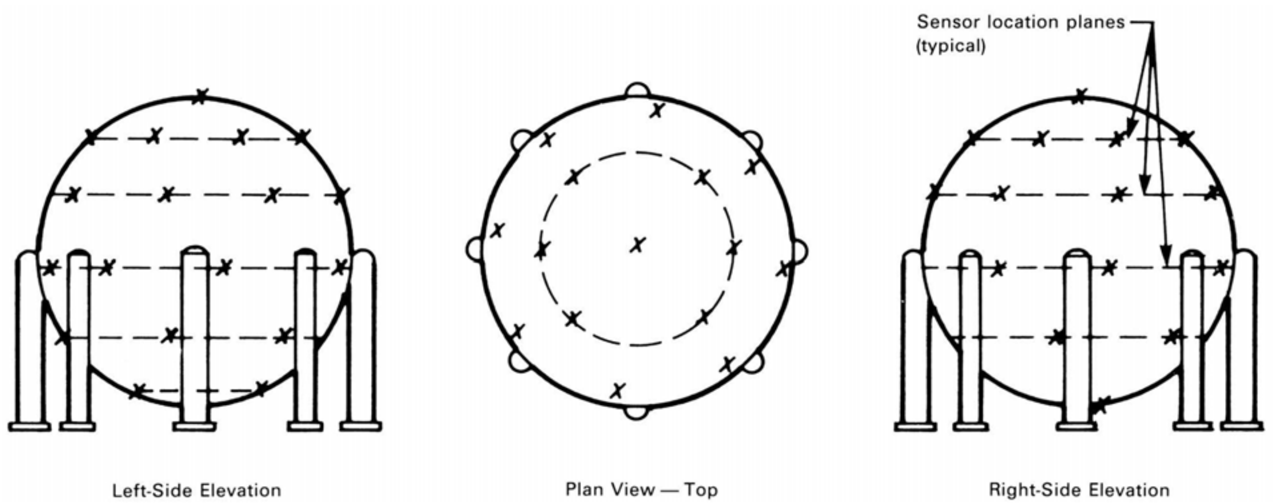
GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional rows of sensors may be required.

Figure A-1240
Case 4 — Vertical Pressure Vessel Packed or Trayed Column Dished Heads, Lug or Skirt Supported



GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Special areas may require additional sensors.
(3) Additional rows of sensors may be required.

Figure A-1250
Case 5 — Spherical Pressure Vessel, Leg Supported



GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional sensors may be required.

NONMANDATORY APPENDIX B
SUPPLEMENTAL INFORMATION FOR CONDUCTING ACOUSTIC EMISSION EXAMINATIONS

B-1210 FREQUENCY SELECTION

The frequency band of 100 kHz to 200 kHz is the lowest frequency band that should be considered for general AE pressure vessel examination. Higher frequency bands may be considered if background noise cannot be eliminated. If a higher frequency band is used the following items must be considered.

(a) Attenuation characteristics will change.

(b) Sensor spacings will decrease and more sensors will be required to adequately cover the evaluation area.

(c) Instrumentation performance requirements described in Article 12, Mandatory Appendix I must be adjusted to the higher frequency band.

(d) Instrumentation calibration described in Article 12, Mandatory Appendix I must be performed at the higher frequency band.

(e) Alternate evaluation/acceptance criteria must be obtained from the referencing Code Section.

B-1220 COMBINING MORE THAN ONE SENSOR IN A SINGLE CHANNEL

Two or more sensors (with preamplifiers) may be plugged into a single channel to overcome the effects of local shielding in a region of the vessel. One specific example of this is the use of several sensors (with preamplifiers around a manway or nozzle).

B-1230 ATTENUATIVE WELDS

Some have been shown to be highly attenuative to nonsurface waves. This situation predominantly affects multichannel source location algorithms. This situation can be identified by modifying the attenuation characterization procedure to produce a stress wave which does not contain surface waves traveling across the weld.

B-1240 PRODUCTION LINE TESTING OF IDENTICAL VESSELS

For situations which involve repeated tests of identical vessels where there is no change in the essential variables such as material, thickness, product form and type, the requirement for attenuation characterization on each vessel is waived.

ARTICLE 13
CONTINUOUS ACOUSTIC EMISSION MONITORING OF PRESSURE BOUNDARY COMPONENTS

T-1310 SCOPE

This Article describes the requirements for the use of acoustic emission (AE) continuous monitoring of metal or nonmetal pressure boundary components used for either nuclear or non-nuclear service. Monitoring is performed as a function of load (such as from changes in pressure, temperature, and/or chemistry) over time.

When AE monitoring in accordance with this Article is required, the user shall specify the following:

(a) personnel qualification/certification requirements

(b) extent of examination and/or area(s)/volume(s) to be monitored

(c) duration of monitoring period

(d) acceptance/evaluation criteria

(e) reports and records requirements

When this Article is specified by a referencing Code Section, the technical requirements described herein shall be used together with Article 1, General Requirements. Definitions of terms used in this Article appear in Article 1, Mandatory Appendix I, I-121.8 (AE — Acoustic Emission).

Generic requirements for continuous AE monitoring of pressure boundary components during operation are addressed within this Article. Supplemental requirements for specific applications such as nuclear components, nonmetallic components, monitoring at elevated temperatures, limited zone monitoring, and leak detection are provided in the Mandatory Appendices to this Article.

T-1311 REFERENCES

The following references contain additional information that should be considered for use in the application of this Article.

(a) SE-650, Standard Guide for Mounting Piezoelectric Acoustic Emission Sensors

(b) SE-750, Standard Practice for Characterizing Acoustic Emission Instrumentation

(c) SE-976, Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

(d) SE-1067, Standard Practice for Acoustic Emission Examination of Fiber Reinforced Plastic Resin (FRP) Tanks/Vessels

(e) SE-1118, Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

(f) SE-1139, Standard Practice for Continuous Monitoring of Acoustic Emission from Metal Pressure Boundaries

(g) SE-1211, Standard Practice for Leak Detection and Location using Surface-Mounted Acoustic Emission Sensors

T-1320 GENERAL

Continuous AE monitoring is used to detect, locate, and characterize AE sources in pressure boundaries. Analysis of the AE response signals is used to evaluate the pressure boundary structural integrity. These AE sources are limited to those activated during normal plant system operation. In the context of this Article, normal system operation may include upsets, routine pressure tests performed during plant system shutdown as well as operation during startups and shutdowns.

Monitoring is performed using AE sensors that are installed in key locations and connected to an AE instrument capable of recording and storing AE data generated during normal plant system operation. In addition, the AE instrument may be used to collect and store data that helps determine the load that is being applied to the pressure boundary.

T-1321 RELEVANT INDICATIONS

All relevant indications detected during AE monitoring shall be evaluated to determine if further evaluation by other methods of nondestructive examination is required.

T-1322 PERSONNEL QUALIFICATION

In accordance with the referencing Code Section the requirements for personnel qualification and certification should be specified.

T-1323 WRITTEN PROCEDURES

A written procedure shall be established. The details of the outline are as follows:

(a) the type of equipment to be used

(b) how the equipment is to be installed

(c) calibration and checkout of equipment performance

(d) the type of data to be collected, stored, and archived

(e) how data is to be analyzed and the results reported

(f) record keeping

The referencing Code Section should specify any other details as well as the means for accepting the written procedures.

T-1330 EQUIPMENT

T-1331 GENERAL

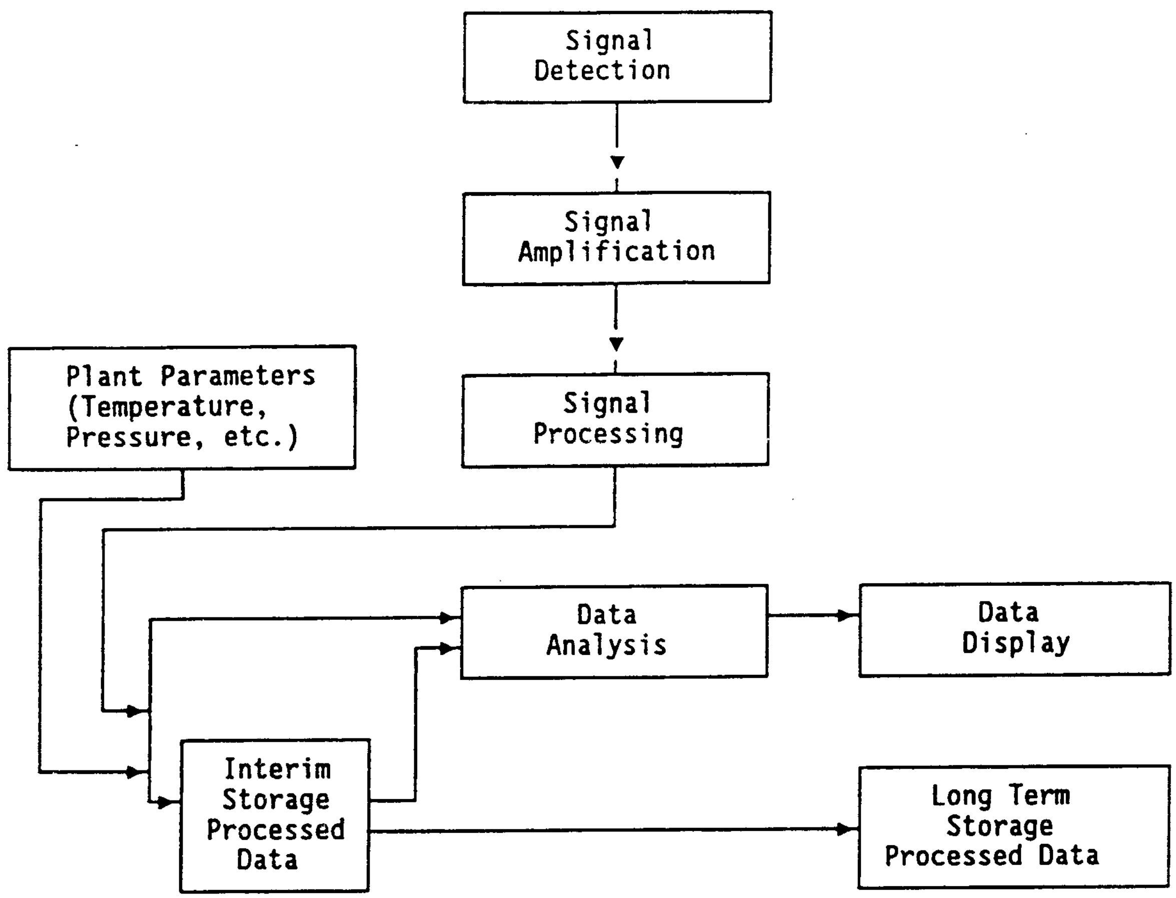
The AE monitoring system consists of sensors, preamplifiers, amplifiers, filters, signal processors, and a data storage device together with interconnecting cables or wireless transmitters and receivers. Simulated AE source(s) and auxiliary equipment such as pressure gauges and temperature sensors are also required. The AE monitoring system shall provide the functional capabilities shown in Figure T-1331.

T-1332 AE SENSORS

Sensors shall be one of two general types: those mounted directly on the surface of the component being monitored, and those that are coupled to the surface of the component by the use of a waveguide. Sensors shall be acoustically coupled to the surface of the component being monitored and be arranged and located per the requirements of the written procedure. Selection of sensor type shall be based on the application; i.e., low or high temperature, nuclear or non-nuclear, etc. The sensor selected for the specific application shall be identified in the written procedure. The sensor system (i.e., sensors, preamplifiers, and connecting cables) used to detect AE shall limit electromagnetic interference to a level not exceeding 27 dB_{AE} where dB_{AE} is the amplitude of the sensor output based on a reference voltage of 1 μV.

T-1332.1 Sensor Response Frequency. For each application, selection of the sensor response bandpass frequencies shall be based on a characterization of background noise and sensor response in terms of amplitude vs. frequency. The lowest frequency compatible with avoiding interference from background noise should be used to maximize sensitivity of AE signals and minimize signal attenuation.

Figure T-1331
Functional Flow Diagram — Continuous AE Monitoring System



T-1332.2 Differential, Integrated, and Tuned Sensors. Three sensor designs have been effective in overcoming noise interference problems. One is a differential sensor that cancels out electrical transients entering the system through the sensor. The second is the integrated sensors with built-in preamplifiers and frequency filters. The third design is an inductively tuned sensor that operates to shape the sensor response around a selected frequency; i.e., inductive tuning allows discrimination against frequencies on either side of a selected response frequency as shown in Figure T-1332.2. These sensor designs may be used separately or together.

T-1332.3 Sensor Mounting. Sensors shall be mounted to the component surface using three basic methods.

T-1332.3.1 Bonding. Bond directly to the surface with an adhesive. The chemical content of the adhesive shall be checked to assure that it is not deleterious to the surface of the component.

T-1332.3.2 Pressure Coupling. Pressure coupling to the surface using either a strap or a magnetic mount. A thin, soft metal interface layer between the sensor and the surface is often effective for achieving acoustic coupling with minimal pressure.

T-1332.3.3 Waveguides. In the case of waveguide sensors, the tip of the waveguide may be shaped to reduce the required force to maintain acoustic coupling. The sensor itself may be bonded or pressure coupled to the waveguide.

T-1332.4 Couplant. Couplant shall provide consistent coupling efficiency for the duration of the test. Coupling efficiency shall be verified as required in T-1350.

T-1333 SIGNAL CABLES

Coaxial cables shall be used to connect the analog AE signals from the sensors to the monitoring instrument (monitor). Whenever a protective barrier or containment structure must be penetrated using a bulkhead fitting or penetration plug to transmit signals from the sensor to the monitor, extreme care must be taken to avoid incurring excessive signal loss or noise that reduces the useable dynamic range. When the coaxial (signal) cables are used to supply DC power to the preamplifiers/line drivers, they shall be terminated with the appropriate characteristic impedance.

Power and signal cables shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB/ft (3.3 dB/m) of cable length. Maximum cable length shall be 500 ft (150 m) unless a line driver is used.

T-1334 AMPLIFIERS

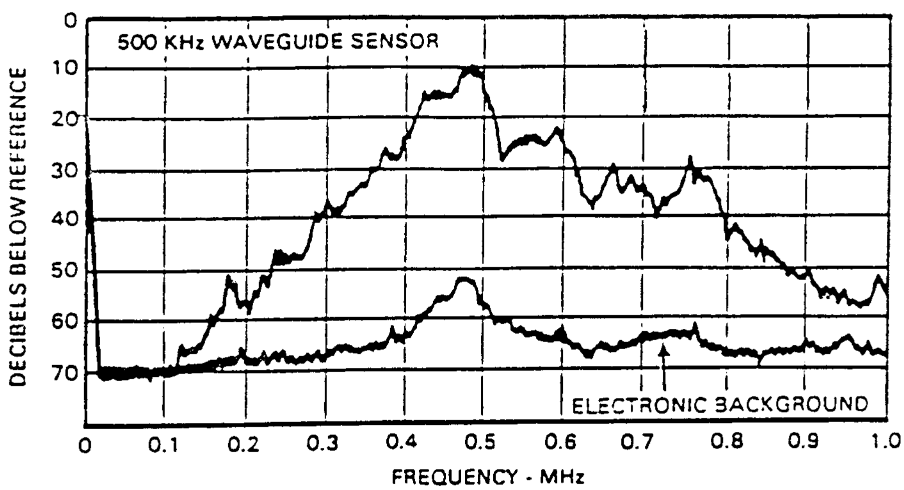
At least one preamplifier shall be used with each sensor to amplify the AE signals for transmission to the monitor. Where long signal cables are required, a preamplifier and line driver between the sensor and the monitor may be required.

With the high signal amplification required to detect AE signals, the internal noise of the preamplifiers must be minimized to avoid interference with AE signal detection. The frequency response band of the amplifiers shall be matched to the response profile determined for the AE sensors. (See Article 13, Mandatory Appendix II.)

T-1335 AE INSTRUMENT AND MONITOR

The AE instrument and monitor shall include a post amplifier, a signal discrimination function, and a signal processing module for each signal channel. A stable,

Figure T-1332.2
Response of a Waveguide AE Sensor Inductively Tuned to 500 kHz



grounded electrical power supply should be used. The monitor shall also include a video display function that can be used to display AE data as well as a data storage capability suitable for long-term, nonvolatile data storage. A data analysis function may be integral with the AE monitor or be a separate function that draws from the stored AE data.

The post amplifier shall meet the requirements of T-1334. The AE monitor shall be capable of processing and recording incoming data at a rate of at least 50 hits/sec for all channels simultaneously for an indefinite time period and at a rate of at least 100 hits/sec for all channels simultaneously for any 15-sec period.

T-1335.1 AE Signal Discrimination. A real-time signal discrimination function to process incoming signals and identify relevant AE signals shall be included. The discrimination function may either exclude all signals not identified as from flaw growth, or flag those signals identified as flaw growth while accepting all signals above the voltage threshold.

T-1335.2 Signal Processing. The dynamic range of the signal processor shall be at least 80 dB for each parameter being measured. The signal processor shall be controlled by voltage threshold circuits that limit accepted data to signals that exceed the voltage amplitude threshold. The voltage threshold shall be determined on the basis of the background noise.

Signal parameters to be measured shall include AE hit count, total number of signal hits at each sensor, signal peak amplitude, time for threshold crossing to signal peak, measured area under the rectified signal envelope (MARSE) in V-sec, and difference in time of signal arrival (Δt) at all sensors in a sensor array used for AE source location. In addition to the AE signal features above, other AE features such as energy, signal strength, true energy, and absolute energy may be measured along with clock time, date, and the value of plant parameters (internal pressure, temperature, etc.). Plant parameters that are identified as significant to flaw growth and associated with the time of signal detection shall be recorded. The signal processor section shall also measure the overall RMS background signal level for each sensing channel [and/or average signal level (ASL) in dB] for leak detection purposes.

T-1340 MISCELLANEOUS REQUIREMENTS

T-1341 EQUIPMENT VERIFICATION

Acceptable performance shall be defined per the written procedure (T-1323). Dynamic range of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals (e.g., I-1341) from the waveform generator shall be input to each preamplifier to verify that the signal amplification, data processing functions, data processing rate, and data analysis, display, and storage meet the requirements of this Article.

NOTE: AE signal source location performance is tested under T-1362.1.

With the AE monitor gain set at operating level, the system shall be evaluated according to the written procedure using input signals that test both the low and high ends of the dynamic range of the AE monitor system. Signal frequencies shall include samples within the range of intended use.

T-1342 SENSOR CALIBRATION

T-1342.1 Sensor Sensitivity and Frequency Response. Each sensor shall produce a minimum signal of $0.1 mV_{peak}$ referred to the sensor output at the selected monitoring frequency when mounted on a calibration block and excited with a helium gas jet as described in SE-976. Appropriate calibration blocks are identified in the Appendices as a function of specific applications. Helium gas excitation shall be performed using a 30 psi (200 kPa) helium source directed onto the surface of the calibration block through a #18 hypodermic needle held perpendicular to the calibration block surface. The needle tip shall be a maximum of $^1/_8$ in. (3 mm) above the surface of the block and a maximum of $1^1/_2$ in. (38 mm) from the mounted sensor. The process may also be used to verify the sensor response profile in terms of frequency to assure that the response roll-off on either side of the selected monitoring frequency is acceptable.

An optional technique that may be used for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique, per SE-976.

T-1342.2 Uniformity of Sensor Sensitivity. The sensitivity of each sensor shall be evaluated by mounting it on a calibration block as it will be mounted on the plant component and measuring its response to the energy produced by fracturing a 0.012 in. (0.3 mm), 2H pencil lead against the surface of the block in accordance with SE-976 at a point approximately 4 in. (100 mm) from the center of the sensor. When performing this evaluation, it is useful to use a 40 dB preamplifier with the sensor to produce an adequate output signal for accurate measurement. The peak response of each sensor to the simulated AE signal shall be within 3 dB from the average for all sensors at the selected monitoring frequency.

T-1343 SIGNAL PATTERN RECOGNITION

If AE signal pattern recognition is used, this function shall be demonstrated and qualified as follows:

(a) Assemble the AE monitor including two representative sensors mounted on a calibration block with the same sensor mounting (T-1332.3) process to be used for monitoring. The sensors shall be excited 10 times by each of the following three methods:

(1) Break a 0.012 in. (0.3 mm), 2H pencil lead against the surface of the block in accordance with SE-976.

(2) Drop onto the surface of the block a $^1/_4$ in. (6 mm) diameter steel ball from a height sufficient to produce a response from the sensors that does not saturate the AE monitor.

(3) Inject a multicycle (five cycles minimum) burst signal into the block with a transducer and waveform generator.

(b) The pattern recognition function shall identify at least 8 out of 10 lead fracture signals as AE crack growth signals and at least 8 out of 10 of each other type signals as signals not associated with crack growth.

T-1344 MATERIAL ATTENUATION/ CHARACTERIZATION

Prior to installation of AE system for monitoring plant components, the acoustic signal attenuation in the material shall be characterized. This is necessary for determining the sensor spacing for effective AE detection. Attenuation measurements shall be made at the frequency selected for AE monitoring and shall include both surface and bulk wave propagation. The attenuation measurements should be performed with the material temperature within ±20°F (±11°C) of the expected temperature during actual component monitoring.

T-1345 BACKGROUND NOISE

The AE system signal level response to continuous process background noise shall not exceed 55 dB_{AE} output. This shall be achieved by restricting the frequency response of the sensor system. Reducing sensitivity is not acceptable.

T-1346 VERIFICATION RECORDS

Documentation of the equipment verification process shall include the following:

(a) a copy of the equipment verification procedure

(b) personnel qualification records

(c) description of the AE equipment and verification equipment used

(d) verification test

(e) signature of the individual responsible for the verification test

(f) date of the verification

Equipment verification records shall be retained as part of the monitoring application records.

T-1347 SENSOR INSTALLATION

T-1347.1 Coupling. Acoustic coupling between the sensor and the component surface shall be verified as the sensors are mounted per the written procedure. This can be done by lightly tapping the surface or by performing a pencil lead break test [0.012 in. (0.3 mm), 2H] against the component surface while observing the sensor output. Other simulation methods are acceptable such as pulsing individual sensors. Guidance for sensor mounting is provided in SE-650 and in T-1332.3.

T-1347.2 Array Spacing. A sufficient number of sensors (per the written procedure) shall be located on the component in a multisource array(s) to provide for AE signal detection and source location. Each sensor shall produce an output of at least 30 dB_{AE} when a 0.012 in. (0.3 mm), 2H pencil lead is broken against the bare surface of the component at the most remote location that the sensor is expected to monitor. When a location algorithm is used, the location of each lead break may be surrounded with a material (mastic or putty) to absorb surface waves. A 0.1 in. (2.5 mm) lead extension shall be broken at an angle of approximately 30 deg to the component surface.

T-1347.3 Functional Verification. One or more acoustic signal sources, with an output frequency range of 100 kHz to 700 kHz shall be installed within the monitoring zone of each sensor array for the purpose of periodically testing the functional integrity of the sensors during monitoring. This is not intended to provide a precise sensor calibration but rather a qualitative sensitivity check. It shall be possible to activate the acoustic signal source(s) from the AE monitor location using an AE simulation method.

T-1348 SIGNAL LEAD INSTALLATION

The coaxial cable and other leads used to connect the sensors to the AE monitor shall be capable of withstanding extended exposure to hostile environments as required to perform the monitoring activities.

T-1349 AE MONITOR INSTALLATION

The AE monitor shall be located in a clean, controlled environment suitable for long-term operation of a computer system. The electronic instrumentation (preamplifiers and AE monitor components) shall be located in an area that is maintained at a temperature range of 40°F to 115°F (5°C to 45°C).

T-1350 TECHNIQUE/PROCEDURE REQUIREMENTS

AE monitoring activities shall be performed in accordance with a written procedure. An outline of the written procedure is given in T-1323. In addition, each procedure shall include at least the following information, as applicable:

(a) components to be monitored include dimension, materials of construction, operating environment, and duration of monitoring

(b) a description of the AE system to be used and its capabilities in terms of the functional requirements for the intended application AE system calibration and verification requirements

(1) Manufacturer's Calibration. Purchased AE system components shall be accompanied by manufacturer's certification of performance specifications and tolerances.

(2) Annual Calibration. The instrumentation shall have an annual, comprehensive calibration following the guideline provided by the manufacturer using calibration instrumentation meeting the requirements of a recognized national standard, for example, but not limited to NIST and ANSI.

(c) number, location, and mounting requirements for AE sensors

(d) interval and acceptable performance during the AE system functional check (T-1373.2)

(e) data recording processes and data to be recorded

(f) data analysis, interpretation, and evaluation criteria

(g) supplemental NDE requirements

(h) personnel qualification/certification requirements

(i) reporting and record retention requirements

T-1351 AE SYSTEM OPERATION

A written procedure describing operation of the AE system shall be prepared, approved by a qualified individual, and made available to the personnel responsible for operating the AE system. Each procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1351.1 AE System Operation. Routine operation of the AE system for collection of data may be performed by a qualified individual (T-1322) who has demonstrated knowledge and skills associated with this technology.

T-1351.2 Periodic AE System Verification. AE system operation and data interpretation shall be verified by a qualified individual on approximately monthly intervals. If the system appears to be malfunctioning, relevant signals are detected, or an abrupt change in the rate of AE signals is observed, the system operation shall be verified prior to continued use.

T-1352 DATA PROCESSING, INTERPRETATION, AND EVALUATION

A written procedure for processing, interpreting, and evaluating the AE data shall be prepared and approved by an individual who has demonstrated knowledge and skills associated with this technology. This procedure shall be made available to the personnel responsible for operating the AE system, the personnel responsible for AE data interpretation and evaluation, and a representative of the owner of the plant system being monitored. This procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1353 DATA RECORDING AND STORAGE

Specific requirements for recording, retention, and storage of the AE and other pertinent data shall be prepared per the written procedure or in accordance with the referencing Code.

T-1354 COMPONENT LOADING

Several means of loading pressure boundaries are applicable to continuous AE monitoring. These include

(a) startup

(b) continuous and cyclic operation

(c) shutdown of operating plant systems and components

(d) pressure tests of nonoperating plant systems

(e) thermal gradients

(f) chemical exposure

Load may be introduced by either a combination of applied pressure and thermal gradient. The chemical environment can lead to active corrosion which may also stimulate AE.

This Article describes examination techniques that are applicable during normal operation of pressurized plant systems or components. The pressurizing rate should be sufficient to facilitate the examination with minimum extraneous noise. If required, provisions shall be made for maintaining the pressure at designated hold points. All relevant operating conditions such as pressure, temperature, etc., shall be recorded in real time by the AE instrumentation and displayed historically (e.g., Events versus Time).

T-1355 NOISE INTERFERENCE

Noise sources that interfere with AE signal detection should be controlled to the extent possible. For continuous monitoring, it may be necessary to accommodate background noise by monitoring at high frequencies, shielding open AE system leads, using differential sensors, and using special data filtering techniques to reduce noise interference.

T-1356 COORDINATION WITH PLANT SYSTEM OWNER/OPERATOR

Due to operational considerations unique to the AE method, close coordination between the AE monitor operator and the owner/operator of the plant shall be established and maintained. Provisions for this coordination function should be described in the written procedures submitted for approval prior to initiation of AE monitoring activities.

T-1357 SOURCE LOCATION AND SENSOR MOUNTING

Sources shall be located with the specified accuracy by multichannel sensor arrays, zone location, or both using either time or amplitude based methods. The requirements for sensor mounting, placement, and spacing are further defined in the applicable Mandatory Appendices.

T-1360 CALIBRATION

T-1361 SENSORS

The frequency response for each AE channel shall be measured with the sensors installed on a plant pressure boundary component. Sensor response shall be measured at the output of the preamplifier using a spectrum analyzer. The excitation source shall be a helium gas jet directed onto the component surface from a nominal 30 psi (200 kPa) source through a #18 hypodermic needle held perpendicular to the component surface at a maximum stand-off distance of $^1/_8$ in. (3 mm) located a maximum of $1^1/_2$ in. (38 mm) from the mounted sensor. The gas shall not impinge on the sensor or the waveguide. AE sensor peak response to the gas jet excitation at the monitoring frequency shall be at least 40 dB_{AE} referred to the output of the sensor, before any pre-amplification. Any AE sensor showing less than 40 dB_{AE} output shall be reinstalled or replaced, as necessary, to achieve the required sensitivity. An optional technique for determining AE sensor response is the "Pencil Lead Break" technique, which is described in SE-976.

T-1362 COMPLETE AE MONITOR SYSTEM

T-1362.1 Signal Detection and Source Location. The signal detection and source location accuracy for each sensor array shall be measured using simulated AE signals injected on the component surface at not less than 10 preselected points within the array monitoring field. These simulated AE signals shall be generated by breaking 2H pencil leads [0.012 in. (0.3 mm) or 0.020 in. (0.5 mm) diameter] against the component surface at the prescribed points. The pencil leads shall be broken at an angle of approximately 30 deg to the surface using a 0.1 in. (2.5 mm) pencil lead extension (see SE-976). The location of each pencil lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. Location accuracies within one wall thickness at the AE source location or 5% of the minimum sensor array spacing distance, whichever is greater, are typical. All location accuracies shall be demonstrated and documented.

T-1362.2 Function Verification. Response of the AE system to the acoustic signal source described in T-1347.3 shall be measured and recorded for reference during later checks of the AE system.

T-1363 VERIFICATION INTERVALS

The performance of the installed AE monitor system shall be verified in accordance with T-1360 at the end of each plant operating cycle or when the data indicates potential abnormal operation.

T-1364 VERIFICATION RECORDS

A written log recording the verification values shall be maintained at the location of the system. Documentation of the installed system verification shall include the following:

(a) a copy of the verification procedure(s)

(b) personnel certification records

(c) description of the AE equipment and the verification equipment used

(d) quantitative results of the verification

(e) signature of the individual responsible for the verification

(f) date(s) of the verification(s)

Retention of the verification records shall be in accordance with T-1393.

T-1370 EXAMINATION

T-1371 PLANT STARTUP AND SHUTDOWN

During plant startup and shutdown, the AE rate and source location information shall be evaluated continuously until it has been determined that the plant is in shutdown or back on line and no flaw data is being generated. The AE RMS voltage signal level (or ASL) shall also be evaluated for indications of pressure boundary leaks. These parameters should be monitored automatically by the AE monitor and generate an automatic alarm or alert for any abnormal condition.

T-1373 PLANT STEADY-STATE OPERATION

T-1373.1 Data Evaluation Interval. AE data shall be evaluated per the written procedure (or continuously by AE monitors which have the ability to generate alarms automatically) during normal plant operation. The AE data shall also be evaluated when

(a) a sustained AE activity rate is detected from one or more sensors

(b) cluster locations are observed concentrated within a diameter of 3 times the wall thickness of the component or 10% of the minimum sensor spacing distance in the array, whichever is greater

(c) also refer to Article 13, Mandatory Appendices II and III.

T-1373.2 AE System Functional Check. AE system response to the installed acoustic signal source shall be evaluated periodically as specified in the procedure. Deterioration of sensitivity exceeding 4 dB for any channel shall be recorded and the affected component shall be replaced at the earliest opportunity.

T-1374 NUCLEAR METAL COMPONENTS

Specific and supplemental examination requirements for nuclear metal components are specified in Article 13, Mandatory Appendix I.

T-1375 NON-NUCLEAR METAL COMPONENTS

Specific and supplemental examination requirements for non-nuclear metal components are specified in Article 13, Mandatory Appendix II.

T-1376 NONMETALLIC COMPONENTS

Specific and supplemental examination for nonmetallic components are specified in Article 13, Mandatory Appendix III.

T-1377 LIMITED ZONE MONITORING

Specific and supplemental examination requirements for limited zone monitoring are specified in Article 13, Mandatory Appendix IV.

T-1378 HOSTILE ENVIRONMENT APPLICATIONS

Specific and supplemental examination requirements for hostile environment applications are specified in Article 13, Mandatory Appendix V.

T-1379 LEAK DETECTION APPLICATIONS

Specific and supplemental examination requirements for leak detection applications are specified in Article 13, Mandatory Appendix VI.

T-1380 EVALUATION/RESULTS

T-1381 DATA PROCESSING, INTERPRETATION, AND EVALUATION

Data processing, interpretation, and evaluation shall be in accordance with the written procedure (T-1350) for that specific application and the applicable Mandatory Appendices.

T-1382 DATA REQUIREMENTS

The following data shall be acquired and recorded:

(a) AE event count versus time for each monitoring array

(b) AE source and/or zone location for all acoustic signals accepted

(c) AE hit rate for each AE source location cluster

(d) relevant AE signal parameter(s) versus time for each data

(e) channel

(f) location monitored, date, and time period of monitoring

(g) identification of personnel performing the analysis

In addition, the data records shall include any other information required in the applicable procedure (T-1350).

T-1390 REPORTS/RECORDS

T-1391 REPORTS TO PLANT SYSTEM OWNER/OPERATOR

T-1391.1 Summary of Results. A summary of AE monitoring results shall be prepared in accordance with the procedure (T-1350).

T-1391.2 Unusual Event Reporting Requirements. Reporting of unusual AE indications shall be as specified in the procedure (T-1350).

T-1391.3 Monitoring Data and Evaluation Criteria. A summary report on the correlation of monitoring data with the evaluation criteria shall be provided to the plant system owner/operator as specified in the procedure.

T-1391.4 Comprehensive Report. Upon completion of each major phase of the monitoring effort (as described in T-1371 and T-1373), a comprehensive report shall be prepared in accordance with the procedure (T-1350). This report shall include the following:

(a) complete identification of the plant system/component being monitored including material type(s), method(s) of fabrication, manufacturer's name(s), and certificate number(s)

(b) sketch or manufacturer's drawing with component dimensions and sensor locations

(c) plant system operating conditions including pressurizing fluid, temperature, pressure level, etc.

(d) AE monitoring environment including temperature, radiation and corrosive fumes if appropriate, sensor accessibility, background noise level, and protective barrier penetrations utilized, if any

(e) a sketch or manufacturer's drawing showing the location of any zone in which the AE response exceeded the evaluation criteria

(f) any unusual events or observations during monitoring

(g) monitoring schedule including identification of any AE system downtime during this time period

(h) names and qualifications of the AE equipment operators

(i) complete description of the AE instrumentation including manufacturer's name, model number, sensor types, instrument settings, calibration data, etc.

T-1392 RECORDS

T-1392.1 Administrative Records. The administrative records for each AE monitoring application shall include the applicable test plan(s), procedure(s), operating instructions, evaluation criteria, and other relevant information, as specified by the user or in accordance with the referencing Code Section. A real time data log shall be kept that identifies the date, time, person reviewing the AE data, and any comments on the data or activity. The remote log shall be located on the main computer and form part of the monthly report.

T-1392.2 Equipment Verification and Calibration Data. The pre-installation and post-installation AE system verification and calibration records including signal attenuation data and AE system performance verification checks shall be retained per the referencing Code Section.

T-1392.3 Raw and Processed AE Data. The raw data records (identified in T-1382) shall be retained at least until the AE indications have been independently verified by other qualified tests. The retention period for the processed data records shall be as specified in the procedure (T-1350).

T-1393 RECORD RETENTION REQUIREMENTS

All AE records shall be maintained as required by the referencing Code Section and the procedure (T-1350).

MANDATORY APPENDIX I
NUCLEAR COMPONENTS

I-1310 SCOPE

This Appendix specifies supplemental requirements for continuous acoustic emission (AE) monitoring of metallic components in nuclear plant systems. The requirements of Article 13, Mandatory Appendix V (Hostile Environment Applications) shall also apply to continuous AE monitoring of nuclear plant systems.

I-1330 EQUIPMENT

I-1331 PREAMPLIFIERS

The internal electronic noise of preamplifiers shall not exceed 7 μV rms referred to the input with a 50-Ω input termination. The frequency response band of the amplitude shall be matched to the response profile determined for the AE sensors.

I-1332 AE SENSORS

Sensors shall be capable of withstanding the ambient service environment (i.e., temperature, moisture, vibration, and nuclear radiation) for a period of 2 yr. Refer to V-1330 for additional sensor requirements. In monitoring nuclear components, in addition to high temperature [~600°F (320°C) in most locations], the environment at the surface of the component may also include gamma and neutron radiation. For neutron radiation, a waveguide may be used to isolate the sensor and preamp from the neutron radiation field.

I-1333 FREQUENCY RESPONSE

The frequency response band of the sensor/amplifier combination shall be limited to avoid interference from background noise such as noise caused by coolant flow. Background noise at locations to be monitored shall be characterized in terms of intensity versus frequency prior to selection of the AE sensors to be used. This information shall be used to select the appropriate frequency bandwidth for AE monitoring. The sensor frequency roll off below the selected monitoring frequency shall be at a minimum rate of 15 dB per 100 kHz, and may be achieved by inductive tuning of the sensor/preamplifier combination. The high end of the frequency response band should roll off above 1 MHz at a minimum rate of 15 dB per octave to help reduce amplifier noise. These measurements shall be made using the helium gas jet technique described in T-1342.1 and T-1361.

I-1334 SIGNAL PROCESSING

The threshold for all sensor channels shall be set at a minimum of 10 dB above the sensor channel background noise level but with all channels set the same.

I-1340 MISCELLANEOUS REQUIREMENTS

I-1341 EQUIPMENT QUALIFICATION

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input to each preamplifier to verify that the signal amplification, data processing functions, data processing rate, and data analysis, display, and storage meet the requirements of this Article.

NOTE: AE signal source location performance is tested under T-1362.1.

The system shall be evaluated using input signals of 0.5 mV and 10.0 mV peak-to-peak amplitude, 0.5 msec (millisecond) and 3.0 msec duration, and 100 kHz, and 1.0 MHz frequency from the waveform generator.

I-1360 CALIBRATION

I-1361 CALIBRATION BLOCK

The calibration block shall be a steel block with minimum dimensions of 4 in. × 12 in. × 12 in. (100 mm × 300 mm × 300 mm) with the sensor mounted in the center of a major face using the acoustic coupling technique to be applied during in-service monitoring.

I-1362 CALIBRATION INTERVAL

The installed AE monitor system shall be recalibrated in accordance with T-1360 during each refueling or maintenance outage, but no more often than once every 24 months.

I-1380 EVALUATION

(a) The monitoring procedure (T-1350) shall specify the acceptance criteria for crack growth rate.

(b) The AE data shall be evaluated based on AE rate derived from the number of AE signals (per second) accepted by the signal identification function and identified with a specific area of the pressure boundary.

(c) The data shall be analyzed to identify an increasing AE rate that is indicative of accelerating crack growth.

(d) The quantitative crack growth rate shall be estimated using the relationship:

$$da/dt = 290(d\mathrm{AE}/dt)^{0.53}\,(\text{microinches/second})$$
$$= 7366(d\mathrm{AE}/dt)^{0.53}\,(\text{nanometers/second})$$

where

da/dt = crack growth rate

$d\mathrm{AE}/dt$ = the AE rate [as defined in (b) above] in events/second

(e) If the estimated crack growth rate exceeds the acceptance criteria, the flaw area shall be examined with other NDE methods at the earliest opportunity.

MANDATORY APPENDIX II
NON-NUCLEAR METAL COMPONENTS

II-1310 SCOPE

This Appendix specifies supplemental requirements for continuous acoustic emission (AE) monitoring of nonnuclear metal components. The principal objective is to monitor/detect AE sources caused by surface and internal discontinuities in a vessel wall, welds, and fabricated parts and components.

II-1330 EQUIPMENT

II-1331 SENSORS

II-1331.1 Sensor Frequency Response. Acoustic emission sensors shall have a resonant response between 100 kHz to 400 kHz. Minimum sensitivity shall be −85 dB referred to 1 V/μbar determined by a face-to-face ultrasonic test. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response. Acoustic emission sensors in a face-to-face ultrasonic test (or equivalent) shall not vary in peak sensitivity by more than 3 dB compared to its original calibration. Refer to ASTM E975 and ASTM E1781.

II-1331.2 Sensor Mounting/Spacing. Sensor location and spacing shall be based on attenuation characterization, with the test fluid in the vessel, and a simulated source of AE. Section V, Article 12 Nonmandatory Appendices should be referenced for vessel sensor placement. Consideration should be given to the possible attenuation effects of welds.

II-1331.3 Sensor Spacing for Multichannel Source Location. Sensors shall be located such that a lead break at any location within the examination area is detectable by at least the minimum number of sensors required for the multichannel source location algorithm, with the measured amplitude specified by the referencing Code Section. Location accuracy shall be within a maximum of 1 wall thickness or 5% of the sensor spacing distance, whichever is greater.

II-1331.4 Sensor Spacing for Zone Location. When zone location is used, sensors shall be located such that a lead break at any location within the examination area is detectable by at least one sensor with a measured amplitude not less than specified by the referencing Code Section. The maximum sensor spacing shall be no greater than one-half the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel produces a measured amplitude equal to the evaluation threshold.

II-1333 AMPLIFIERS

II-1333.1 Preamplifier. The preamplifier shall be located within 6 ft (1.8 m) from the sensor, and differential preamplifiers shall have a minimum of 40 dB of common-mode noise rejection. Frequency response shall not vary more than 3 dB over the operating frequency range of the sensors when attached. Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB of common-mode rejection.

II-1333.2 Main Amplifier. The main amplifier gain shall be within 3 dB over the range of 40°F to 125°F (5°C to 50°C).

II-1334 MAIN PROCESSOR

The main processor(s) shall have circuits for processing sensor data. The main processor circuits shall be capable of processing hits, counts, peak amplitudes, and signal strength or MARSE on each channel, and measure the following:

(a) Threshold. The AE instrument shall have a threshold control accurate to within ±1 dB over its useful range.

(b) Counts. The AE counter circuit shall detect counts over a set threshold with an accuracy of ±5%.

(c) Hits. The AE instrument shall be capable of measuring, recording, and displaying hits at rates defined in T-1335.

(d) Peak Amplitude. The AE circuit shall measure peak amplitude with an accuracy of ±1 dB. Useable dynamic range shall be a minimum of 80 dB with 1 dB resolution over the frequency bandwidth used. Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be specified in dB and must be referenced to a fixed gain output of the system (sensor or preamplifier).

(e) Energy. The AE circuit shall measure signal strength or MARSE with an accuracy of ±5%. The useable dynamic range for energy shall be a minimum of 80 dB.

(f) Parametric Voltage. If parametric voltage is measured, it shall be measured to an accuracy of ±2% of full scale.

II-1360 CALIBRATION

II-1361 SYSTEM PERFORMANCE CHECK

Prior to beginning the monitoring period, the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input. The device generating the simulated signal shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency per the procedure outlined in T-1350. On-site system calibration shall verify system operation for threshold, counts, signal strength or MARSE, and peak amplitude. Calibration values shall be within the range of values specified in II-1334.

II-1362 SYSTEM PERFORMANCE CHECK VERIFICATION

Verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again following the test. The peak amplitude response of each sensor to a repeatable simulated AE source at a specific distance from the sensor should be taken prior to and following the monitoring period. The measured peak amplitude should not vary more than ±3 dB from the average of all the sensors. Any channel failing this check should be repaired or replaced, as necessary. The procedure will indicate the frequency of system performance checks.

II-1380 EVALUATION

II-1381 EVALUATION CRITERIA — ZONE LOCATION

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1381 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

Table II-1381
An Example of Evaluation Criteria for Zone Location

	Pressure Vessels (Other Than First Hydrostatic Test) Using Zone Location
Emissions during hold	Not more than E hits beyond time T
Count rate	Less than N counts per sensor for a specified load increase
Number of hits	Not more than E hits above a specified amplitude
Large amplitude	Not more than E hits above a specified amplitude
MARSE or amplitude	MARSE or amplitudes do not increase with increasing load
Activity	Activity does not increase with increasing load
Evaluation threshold, dB	50 dB

GENERAL NOTE: Signal strength may be used in place of MARSE. The variables E, T, and N shall be supplied by the referencing Code Section.

II-1382 EVALUATION CRITERIA — MULTISOURCE LOCATION

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1382 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

Table II-1382
An Example of Evaluation Criteria for Multisource Location

	Pressure Vessels (Other Than First Hydrostatic Test) Using Multisource Location
Emissions during hold	Not more than E hits from a cluster beyond time T
Count rate	Less than N counts from a cluster for a specified load increase
Number of hits	Not more than E hits from a cluster above a specified amplitude
Large amplitude	Not more than E hits from a cluster above a specified amplitude
MARSE or amplitude	MARSE or amplitudes from a cluster do not increase with increasing load
Activity	Activity from a cluster does not increase with increasing load
Evaluation threshold, dB	50 dB or specified in procedure

GENERAL NOTE: Signal strength may be used in place of MARSE. The variables E, T, and N shall be supplied by the referencing Code Section."

MANDATORY APPENDIX III
NONMETALLIC COMPONENTS

III-1310 SCOPE

This Appendix specifies supplemental requirements for continuous monitoring of nonmetallic (fiber reinforced plastic) components.

III-1320 GENERAL

Nonmetallic (FRP) components such as pressure vessels, storage tanks, and piping, are typically used at relatively low temperature. Due to high attenuation and anisotropy of the material, AE methodology has proven to be more effective than other NDE methods.

III-1321 APPLICATIONS

Additional information may be found as follows:

(a) FRP Vessels. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Tanks/Vessels

(b) Atmospheric Tanks. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Vessels, ASNT/CARP Recommended Practice ASTM E1067: Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin Tanks/Vessels

(c) Piping. ASTM E1118 — Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

(d) Metal Pressure Vessels. Section V, Article 12 – Acoustic Emission Examination of Metal Vessels During Pressure Testing

III-1330 EQUIPMENT

III-1331 SENSORS

High attenuation and anisotropy of the material are controlling factors in sensor frequency, source location accuracy, and sensor spacing.

III-1331.1 Sensor Frequency Response. Sensors used for monitoring FRP equipment shall operate in the 20 kHz to 200 kHz frequency range.

(19) ### III-1332 SOURCE LOCATION ACCURACY

(a) When high location accuracy is required, source location techniques shall be used that take into consideration the anisotropy of the FRP material. Sensor spacing shall be no greater than 20 in. (500 mm).

(b) Zone location techniques require the AE signal to hit only one sensor to provide useful location data. Sensor spacing of 5 ft to 20 ft (1.5 m to 6.0 m) may be used to cover large areas or the entire vessel.

III-1360 CALIBRATION (19)

III-1361 ANNUAL FIELD CALIBRATION

Annual field calibration shall be performed with an AE waveform generator to verify performance of the signal processor.

III-1362 PERFORMANCE VERIFICATION

Lead break and/or gas jet performance verification techniques (T-1361 and T-1362.1) shall be performed monthly to check all components including couplant, sensor, signal processor, and display.

III-1363 LOW AMPLITUDE THRESHOLD

Low amplitude threshold (LAT) shall be determined using the 4 ft × 6 ft × $^1/_2$ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The LAT threshold is defined as the average measured amplitude of ten events generated by a 0.012 in. (0.3 mm) pencil (2H) lead break at a distance of 4 ft, 3 in. (1.3 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg to the surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (150 mm) from the 4 ft (1.2 m) side and mid-distance between 6 ft (1.8 m) sides.

III-1364 HIGH AMPLITUDE THRESHOLD

High amplitude threshold (HAT) shall be determined using a 10 ft × 2 in. × 12 in. (3.0 m × 50 mm × 300 mm) clean, mild steel bar. The bar shall be supported at each end on elastomeric or similar isolating pads. The HAT threshold is defined as the average measured amplitude of ten events generated by a 0.012 in. (0.3 mm) pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg to the surface with a 0.1 in. (2.5 mm) extension. The sensor shall be mounted 12 in. (300 mm) from the end of the bar on the 2 in. (50 mm) wide surface.

III-1380 EVALUATION

III-1381 EVALUATION CRITERIA

The monitoring procedure (T-1350) shall specify the acceptance criteria including the following:

(a) AE activity above defined levels indicates that damage is occurring.

(b) Felicity ratio from subsequent loadings to a defined level can indicate the amount of previous damage.

(c) Emission activity during periods of contact load indicates that damage is occurring at an accelerating rate.

(19) III-1382 SOURCE MECHANISM

The evaluation criteria shall be developed to address the following failure mechanisms:

(a) Matrix cracking, fiber debonding, and matrix crazing are characterized by numerous low amplitude acoustic emission signals. Matrix cracking and fiber debonding are generally the first indications of failure. Matrix crazing is normally an indication of corrosion or excessive thermal stress.

(b) Delamination is characterized by high signal strength, medium amplitude AE activity. This type of failure is typically found at joints with secondary bonds.

(c) High amplitude AE activity (over high amplitude threshold) is associated with fiber breakage and is an indication of significant structural damage.

MANDATORY APPENDIX IV
LIMITED ZONE MONITORING

IV-1310 SCOPE

This Appendix specifies supplemental requirements for applications involving limited zone monitoring, where one of the objectives is to consciously limit the area or volume of the component or pressure boundary that is monitored by AE. Typical reasons for limiting the monitored area include the following:

(a) observe the behavior of a known flaw at a specific location,

(b) restrict the AE response to signals emanating from specific areas or volumes of the pressure boundary (e.g., restrict the area monitored by AE to one or more nozzle-to-vessel welds, monitor specific structural welds, etc.),

(c) restrict the AE examination to areas of known susceptibility to failure due to fatigue, corrosion, etc., or

(d) improve the signal-to-noise ratio.

IV-1320 GENERAL

IV-1321 GUARD SENSOR TECHNIQUE

One common signal arrival sequence technique uses guard sensors to limit the area of interest. The guard sensor technique involves placing additional sensors further outside the area of interest than the detection sensors. Signals arriving at a guard sensor before any of the detection sensors are rejected. Signals originating from within the area of interest arrive at a detection sensor before any of the guard sensors and are accepted by the data acquisition and analysis process. The guard sensor technique should be implemented so that it can be used in both real time and in post-test analysis.

IV-1340 MISCELLANEOUS REQUIREMENTS

IV-1341 REDUNDANT SENSORS

Redundant sensors should be considered to provide additional assurance that the failure of a single sensor will not preclude continued operation of the AE system throughout the specified monitoring period.

IV-1350 TECHNIQUE

IV-1351 TECHNIQUES

Limited zone monitoring is accomplished by installing sensors in or around the area of interest. Signals originating from outside the area of interest are excluded from the analysis using techniques such as triangulation, amplitude discrimination, coincidence detection, or signal arrival sequence.

IV-1352 PROCEDURE

When limited zone monitoring is intended, the technique used to accomplish this function shall be described in the procedure (T-1323 and T-1350). Any technique, or combination of techniques, may be utilized to accomplish limited zone monitoring provided the technique(s) is described in the applicable procedure.

IV-1353 OTHER TECHNIQUES

The preceding descriptions of typical limited zone monitoring techniques shall not preclude the use of other techniques to provide this function.

IV-1360 CALIBRATION

During the system calibration performed in accordance with T-1362, the effectiveness of the limited zone monitoring technique(s) shall be demonstrated by introducing artificial AE signals both inside and outside the area of interest. The AE system shall accept at least 90% of the signals that originate inside the area of interest, and reject at least 90% of the signals that originate outside the area of interest.

IV-1380 EVALUATION

Flaw evaluation shall be based on data generated within the limited zone. The user shall determine that signals originating from inside the area of interest are not confused with signals originating from outside the area of interest. This can be accomplished by using some type of simulated AE during normal operation of the pressure boundary in the area or volume specified in IV-1310.

IV-1390 DOCUMENTATION

All reports of data acquired using the limited zone monitoring approach shall clearly and accurately identify the effective area of interest.

MANDATORY APPENDIX V
HOSTILE ENVIRONMENT APPLICATIONS

V-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of pressure-containing components during operation at high temperatures and in other hostile environments. As used herein, high temperature means as any application where the surface to be monitored will exceed 300°F (150°C), which is the nominal upper temperature limit for most general purpose AE sensors. Other hostile environments include corrosive environments, high vapor atmospheres, nuclear radiation, confined space, and wet environments.

V-1330 EQUIPMENT

V-1331 AE SENSORS

For high temperature applications, special high temperature sensors shall be used. There are two basic types of sensors for such applications. Surface mounted sensors constructed to withstand high temperatures and waveguide sensors which remove the sensor's piezoelectric sensor from the high temperature environment through the use of a connecting waveguide. A thin, soft metal, interface layer between the sensor and the component surface has proven effective for reducing the interface pressure required to achieve adequate acoustic coupling.

V-1332 AE SENSOR TYPES

V-1332.1 Surface Mounted Sensors. Sensors to be mounted directly on the surface shall be evaluated for their capability to withstand the environment for the duration of the planned monitoring period. Some sensors rated for high temperature service are limited in the time for which they can survive continuous exposure at their rated temperature.

V-1332.2 Waveguide Sensors. The waveguide sensors described below are suitable for hostile environment applications where the sensor unit (piezoelectric crystal and integral preamplifier) can be placed in a less hostile environment [e.g., lower temperature of about 200°F (93°C)] through the use of a waveguide no more than 20 ft (6 m) long. The length of the waveguide is not an absolute; however, as the waveguide length increases, the signal attenuation in the waveguide also increases.

V-1333 WAVEGUIDE

Waveguides may be used in hostile environments. An example for monitoring components with surface temperatures to 1,800°F (980°C) is shown in Figure V-1333. The length of the waveguide is such that the sensor is located in a cooler environment with temperatures of 200°F (93°C) or cooler. Waveguide lengths may range from 2 ft to 20 ft (0.6 m to 6 m). Typical signal loss [for $^1/_8$ in. (3 mm) diameter Type 308 stainless steel] can be as high as 0.45 dB/ft (1.5 dB/m).

V-1334 AE SIGNAL TRANSMISSION

V-1334.1 Signal Cables. Cables rated for the expected environment shall be used to conduct AE signal information from the AE sensor to a location outside of the environment. Refer also to T-1333 and T-1348.

V-1334.2 Wireless. Where accepted wireless transmission of AE signals from the sensor to a receiver may be used in place of signal cables.

V-1340 MISCELLANEOUS REQUIREMENTS

V-1341 SENSOR MOUNTING

Refer to T-1332.3 for a discussion of sensor mounting. Extreme temperature applications require mechanical mounting with dry pressure coupling of the sensors due to the temperature limitations of glues or epoxies. Sensor mounting fixture designs can utilize stainless steel bands or magnets. If magnets are used, the ability of the magnet to retain its magnetic properties in the temperature environment must be evaluated. The fixture shown in Figure V-1341 has been successfully used in a variety of waveguide sensor applications. One major element of the fixture design is to provide a constant load on the waveguide tip at least 16,000 psi (110 MPa). For the waveguide sensor shown in Figure V-1333 with a waveguide tip diameter of 0.05 in. (1.25 mm), 30 lbf (0.13 kN) for the mounting fixture provides the required interface pressure.

Figure V-1333
Metal Waveguide AE Sensor Construction

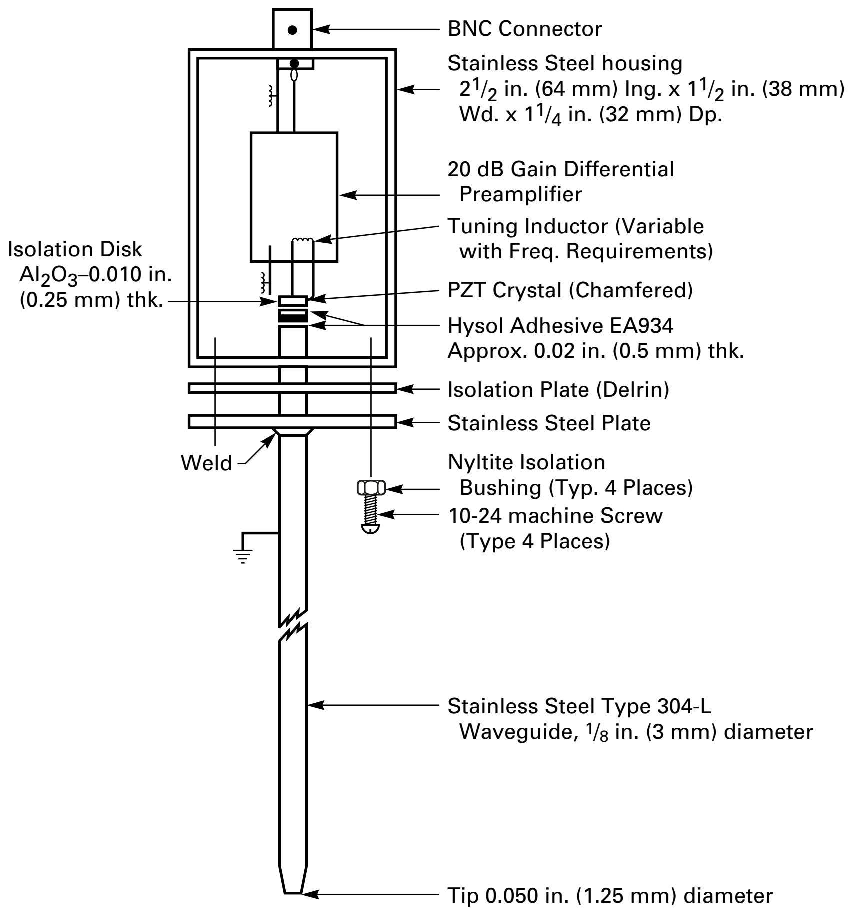
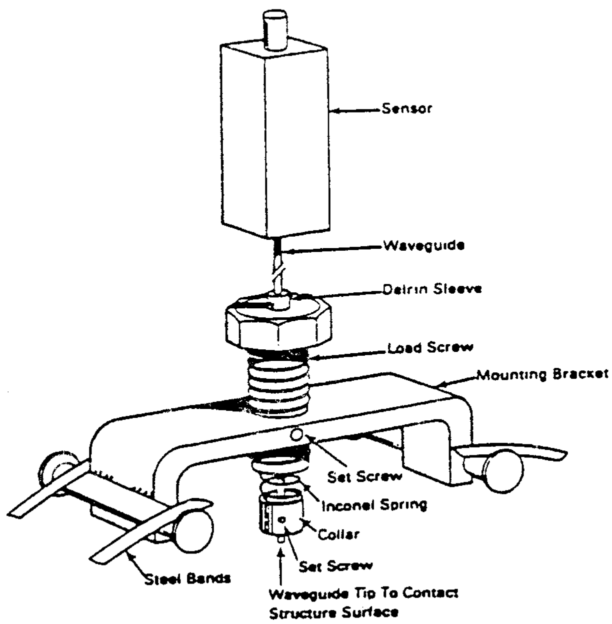


Figure V-1341
Mounting Fixture for Steel Waveguide AE Sensor



MANDATORY APPENDIX VI
LEAK DETECTION APPLICATIONS

VI-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic and nonmetallic components to detect leaks from the pressure boundary. The objective in examining the pressure boundary of systems and components is to assess the leak integrity and identify the leakage area. The requirements of Article 13, Mandatory Appendix I (Nuclear Components) and Article 13, Mandatory Appendix V (Hostile Environment Applications) may also be applicable. SE-1211 should be consulted as a general reference.

VI-1320 GENERAL

The desire to enhance leak detection capabilities has led to research to improve acoustic leak detection technology including technology that is applicable to the pressure boundary of nuclear reactors. Several methods are available for detecting leaks in pressure boundary components including monitoring acoustic noise due to fluid or gas flow at a leakage site. The advantages of acoustic monitoring are rapid response to the presence of a leak and the capability to acquire quantitative information about a leak. Acoustic leak detection methods may be used to detect gas, steam, water, and chemical leaks for both nuclear and non-nuclear applications.

(19) VI-1330 EQUIPMENT

VI-1331 SENSOR TYPE

AE sensor selection is based on optimizing the available dynamic range for a given frequency band, typically 100 kHz to 200 kHz. However, high background noise levels may reduce this dynamic range to an unacceptable level, in which case it may be necessary to select an AE sensor that operates in a higher bandwidth, for example 200 kHz to 500 kHz. Lower background noise levels may allow the user to adopt lower frequency sensors that operate in the 1 kHz to 200 kHz bandwidth. For example, leak detection at frequencies below 100 kHz and as low as 1 kHz may be necessary for leak detection with nonmetallic components.

VI-1331.1 Sensor Selection. Sensor selection shall be based on consideration of the following:

(a) center frequency
(b) bandwidth
(c) ruggedness
(d) response to temperature
(e) humidity
(f) ability of cables and preamplifiers to withstand the specific environment
(g) operating background noise

Using a simulation, sensor response characteristics and curves of leak rate vs. acoustic signal intensity shall be determined before installation to maximize the utility of the information in the acoustic signal.

VI-1331.2 Alternate Sensors. Sensors not specified in this Appendix may be used if they have been shown to meet the specifications in the written procedure for the application and meet the requirements of this Article. Alternate sensors such as accelerometers, microphones, and hydrophones shall be included.

VI-1332 WAVEGUIDE

Waveguides may be used to isolate the sensor from hostile environments such as high temperatures or nuclear radiation for nuclear reactor applications.

VI-1332.1 Design. Waveguide design shall consider the following parameters:

(a) length
(b) diameter
(c) surface finish
(d) material of construction (i.e., ferritic steel, stainless steel, aluminum, and ceramic materials)

VI-1332.2 Coupling. Mandatory Appendix V, V-1341 describes one method for mounting the waveguide. Others that have been shown effective are

(a) welding the waveguide to the pressure boundary
(b) screwing the waveguide into a mounting bracket plate attached to the tensioning apparatus in order to mechanically press the waveguide against the metal component (see Figure V-1341)
(c) screwing the waveguide directly into the pressure boundary component
(d) attaching the sensor directly to the component

Either gold foil or rounded waveguide tips have been shown to be effective when mechanically coupling the waveguide to the pressure boundary component. Occasionally, sensors are mounted and passed through the pressure boundary of a component in order to have the sensor in the process fluid. The sensor(s) shall then be capable of withstanding the ambient service environment of the process fluid. In addition, a safety analysis for installation and monitoring of the system shall be performed.

VI-1333 ELECTRONIC FILTERS

The response of the electronic filter(s) shall be adjustable to achieve the selected monitoring frequency bandwidth of operation as needed (see VI-1331).

VI-1350 TECHNIQUE

VI-1351 PROCEDURE

A calibration procedure shall be established and shall incorporate either the pencil-lead break and/or gas jet techniques described in T-1360 and Article 13, Mandatory Appendix I.

VI-1360 CALIBRATION

VI-1361 CALIBRATION CHECKS

Sensor calibration checks may be conducted by electronically pulsing one of the sensors while detecting the associated acoustic wave with the other sensors.

VI-1370 EXAMINATION

VI-1371 IMPLEMENTATION OF SYSTEM REQUIREMENTS

In order to implement an acoustic leak detection and location system, the following preliminary steps shall be accomplished:

(a) identify the acoustic receiver sites

(b) determine the spacing between waveguides or sensors

(c) meet the sensitivity needs for the system requirements

(d) establish the level of background noise

(e) estimate signal-to-noise ratios as a function of distance and level of background noise for acoustic signals in the frequency range selected

VI-1372 VERIFICATION PROCEDURE

A verification procedure shall be established in the written procedure. During the monitoring period, a self-checking system shall be performed to assure the system is functioning properly.

VI-1373 EQUIPMENT QUALIFICATION AND CALIBRATION DATA

The acoustic equipment qualification and calibration data requirements shall be in accordance with T-1392.

VI-1380 EVALUATION

VI-1381 LEAK INDICATIONS

Detection of a leak or leakage indication near or at a sensor site will be indicated by an increase in the RMS voltage signal or ASL over background noise. The signal increase shall be at least 3 dB or greater above background for a period of at least 30 min.

VI-1382 LEAK LOCATION

The general location of a leak can be established by the analysis of the relative amplitude of the RMS voltage signal or ASL received by the sensor(s). Leak location may also be determined by cross-correlation analysis of signals received at sensors, to either side of the leak site. When leakage location accuracy is desired, it may be necessary to spatially average the correlograms of the acoustic signals at each sensor site by installing an array of sensors. A minimum of three waveguides, separated by a minimum of 4 in. (100 mm), is required for averaging of correlograms. This allows nine correlograms to be generated and averaged for each pair of sensor locations. Self-checking and calibration for the system shall be in accordance with VI-1350. If acoustic background levels are relatively constant, they may also be used to determine whether a probe is failing.

ARTICLE 14 EXAMINATION SYSTEM QUALIFICATION

T-1410 SCOPE

The provisions of this Article for qualifying nondestructive examination (NDE) systems are mandatory when specifically invoked by the referencing Code Section. The organization is responsible for qualifying the examination technique, equipment, and written procedure in conformance with this Article. The referencing Code Section shall be consulted for the following specific detailed requirements:

(a) personnel certification requirements or prerequisites for qualification under the requirements of this Article

(b) examination planning, including the extent of examination

(c) acceptance criteria for evaluating flaws identified during examination

(d) level of rigor required for qualification

(e) examination sensitivity, such as probability of detection and sizing accuracy

(f) records, and record retention requirements

T-1420 GENERAL REQUIREMENTS

T-1421 THE QUALIFICATION PROCESS

The qualification process, as set forth in this Article, involves the evaluation of general, technical, and performance-based evidence presented within the documented technical justification, and when required, a blind or non-blind performance demonstration.

T-1422 TECHNICAL JUSTIFICATION

The technical justification is a written report providing a detailed explanation of the written examination procedure, the underlying theory of the examination method, and any laboratory experiments or field examinations that support the capabilities of the examination method.

The technical justification provides the technical basis and rationale for the qualification, including:

(a) mathematical modeling

(b) field experience

(c) test hierarchy ranking

(d) anticipated degradation mechanism

(e) NDE response by morphology and/or product form

T-1423 PERFORMANCE DEMONSTRATION

The performance demonstration establishes the ability of a specific examination system to achieve a satisfactory probability of detection (POD), by application of the examination system on flawed test specimens. The demonstration test results are used to plot the POD curve and determine the false call probability (FCP) for establishing confidence limitations.

(a) The test specimens shall replicate the object to be examined to the greatest extent practical. Simplified test specimens representative of an actual field situation may be used. The use of specimens with known, identified flaws is preferred, and may be essential for the most rigorous qualification process. A hierarchy of test specimen flaws may be used to minimize qualifications when technically justified (i.e., demonstrations on more challenging degradation mechanisms may satisfy qualification requirements for less challenging mechanisms).

(b) When they sufficiently replicate the object to be tested, performance demonstrations of a limited scope may be used to minimize the costs involved, and facilitate specimen availability. The technical justification must support any limitations to the scope of performance demonstrations.

(c) Personnel qualification shall be based upon blind testing, except where specifically exempted by the referencing Code Section.

(d) The level of rigor applied to the performance demonstration may vary from a simple demonstration on a few flaws, to an extensive test using hundreds of flaws. The level of rigor may also vary between qualifications for the written procedure and examination personnel. More rigorous procedure qualifications can be beneficial for the following reasons:

(1) improved pass-fail rates for personnel;

(2) reduced scope for blind personnel qualification testing;

(3) better understanding of the correlation between the procedure and the damage mechanisms of interest;

(4) more reliable written procedures.

T-1424 LEVELS OF RIGOR

Qualification is performed at one of three levels of rigor. The referencing Code Section shall invoke the required level of rigor, to verify the examination system capability to detect and size typical flaws for the damage mechanisms of interest, depending upon their locations and characteristics. When not otherwise specified, the level of rigor shall be set by agreement between the interested parties. The three levels of rigor are:

(a) Low Rigor (Technical Justification only): The requirement for this level of rigor is a satisfactory technical justification report. No performance demonstrations are required for qualification of the examination system.

(b) Intermediate Rigor (Limited Performance Demonstration): The requirements for this level of rigor are a satisfactory technical justification report, and the successful performance of a demonstration test (blind or nonblind) on a limited number of test specimens. The referencing Code Section shall establish the scope of demonstration requirements, and sets acceptable POD and FCP scores for qualification. When not otherwise specified, the qualification criteria shall be set by agreement between the interested parties.

(c) High Rigor (Full Performance Demonstration): The requirements for this level of rigor are a satisfactory technical justification report, and the successful performance of blind demonstration tests. The referencing Code Section shall establish the scope of demonstration requirements, and sets acceptable POD and FCP scores for qualification. When not otherwise specified, the qualification criteria shall be set by agreement between the interested parties. A sufficient number of test specimens shall be evaluated to effectively estimate sizing error distributions, and determine an accurate POD for specific degradation mechanisms or flaw types and sizes. A high rigor performance demonstration is generally required to support a Probabilistic Risk Assessment.

T-1425 PLANNING A QUALIFICATION DEMONSTRATION

The recommended steps for planning and completing the qualification demonstration, as applicable, are:

(a) Assemble all necessary input information concerning the component, defect types, damage mechanism of interest, and objectives for the examination and qualification of the examination system.

(b) Review the written procedure to verify its suitability for the intended application.

(c) Develop the technical justification for the examination method to be used.

(d) Determine the required level of rigor for the performance demonstration.

(e) Develop performance demonstration criteria using the applicable references.

(f) Conduct the performance demonstration.

(g) Conduct the personnel qualifications.

(h) Compile, document, and evaluate the results.

(i) Determine qualification status, based upon a final evaluation.

T-1430 EQUIPMENT

The equipment used for the performance demonstration of an examination system shall be as specified in the written procedure and the technical justification. After qualification of the examination system, the use of different examination equipment may require requalification (see T-1443).

T-1440 APPLICATION REQUIREMENTS

T-1441 TECHNICAL JUSTIFICATION REPORT

Prior to qualification of any examination system, regardless of the level of rigor, a technical justification report shall be prepared and receive approval by a Level III certified for the specific method to be applied. The technical justification report shall be reviewed and accepted by the owner of the object of interest and, where applicable, to the Jurisdiction, Authorized Inspection Agency (AIA), independent third party, examination vendor, or other involved party. Acceptance of this report by the involved parties is the minimum requirement for qualification of an examination system at the lowest level of rigor. The technical justification report shall address the following minimum topics:

T-1441.1 Description of Component/Flaws to Be Examined. The component design, range of sizes, fabrication flaw history, and any anticipated damage mechanisms (for in-service evaluations) for the object of interest shall be analyzed to determine the scope of the examinations, the types and sizes of critical flaws to be detected, and the probable location of flaws. The scope of the written procedure shall define the limits for application of the procedure (e.g., materials, thickness, diameter, product form, accessibility, examination limitations, etc.).

(a) The flaws of interest to be detected; their expected locations, threshold detection size, critical flaw size, orientation, and shape shall be determined, serving as a guideline for development of the written procedure. Critical flaw sizes (calculated from fracture mechanics analysis) and crack growth rates are important considerations for determining flaw recording and evaluation criteria. The minimum recordable flaw size must be smaller than the critical flaw size, and include consideration of the estimated or observed crack growth rates and the observed quality of workmanship during fabrication. Flaw evaluation must be based upon precluding the formation of critically sized flaws prior to the next inspection, or for the estimated remaining life of the object during normal operations.

(b) Object or technique geometry, environmental conditions, examination limitations, and metallurgical conditions may limit the accessibility for evaluating the object.

Examination procedure or equipment modifications may be required to gain access to the area of interest to be examined.

(c) The acceptance criteria for the demonstration shall be provided.

(d) Additional issues to consider for inclusion in the technical justification may include:

(1) historical effectiveness of procedure;

(2) documentation for prior demonstrations;

(3) extent of prior round robin tests;

(4) observed flaw detection rates, probability of detection, and false call rates;

(5) acceptable rejection/acceptance rates; and

(6) sizing accuracy.

T-1441.2 Overview of Examination System. A general description of the examination system, with sufficient detail to distinguish it from other systems, shall be included within the technical justification report. The description shall include, as applicable, sizing techniques, recording thresholds, and techniques to be used for interpreting indications. If a combination of equipment is used, the applicable conditions for specific equipment combinations shall be adequately described.

T-1441.3 Description of Influential Parameters. The influence of inspection parameters on the examination system shall be considered, including equipment selection, sensitivities, instrument settings, data analysis, and personnel qualifications. The justification for parameter selections shall be based upon the flaws of interest, and include an explanation of why the selected parameters will be effective for the particular examination and expected flaws.

(a) Procedure requirements, including essential variables to be addressed, may be found in the Mandatory Appendix associated with the examination method, or in the referencing Code Section.

(b) Personnel certification requirements, in addition to method specific Level II or III certification, may be advisable under some conditions. When using established techniques for a low rigor application (e.g., for examination of more readily detected damage mechanisms, or where less critical components are involved) a method specific Level II or III certification is adequate. When an intermediate or high rigor application is required, additional personnel requirements shall be considered and, if required, so specified. This may include quantitative risk based criteria for the selection of components to be examined, or completion of a blind performance demonstration. For examination techniques performed by a team of examiners, the specific qualification requirements for each team member shall be addressed.

T-1441.4 Description of Examination Techniques. A justification for the effectiveness of the selected examination technique used in the written procedure for detecting flaws of interest shall be included. The sensitivity settings for recording flaws, flaw orientation, critical flaw size, anticipated degradation mechanism (for in-service applications), and the influence of metallurgical and geometric affects shall be addressed in the justification. A description of the method for distinguishing between relevant and nonrelevant indications, justification for sensitivity settings, and the criteria for characterizing and sizing flaws shall be included.

T-1441.5 Optional Topics for Technical Justification. The following topics may be addressed within the technical justification to improve the understanding of the techniques to be applied.

(a) Description of Examination Modeling. A description of the examination modeling used to develop the procedure, plot indications, predict flaw responses, design mockups, show coverage, and qualify written procedures may be included. Models are required to be validated before use. The referencing Code Section shall establish the criteria for validating models. When not otherwise specified, the modeling validation criteria shall be set by agreement between the interested parties. Models can be used with qualified written procedures to demonstrate the anticipated effectiveness of procedure revisions when parameters such as geometry, angle, size, and access limitations are changed. The written procedure may be qualified or requalified using a minimum number of mockups with adequate justification.

(b) Description of Procedure Experience. Prior experience with a written procedure may be included in the technical justification, and used to support revisions to the procedure. Documentation of similar demonstrations relevant to the proposed examination may be included. Experimental evidence to show the effect of applicable variables may also be cited and considered when developing the written procedure.

T-1442 PERFORMANCE DEMONSTRATION

Examination systems requiring qualification at intermediate or high levels of rigor shall also pass a performance demonstration. The specimen test set and pass/fail criteria to be used in the performance demonstration shall be determined by the owner of the object; and, where applicable, shall be acceptable to the Jurisdiction, Authorized Inspection Agency, independent third party, examination vendor, inspection agency, or other involved party.

(a) The procedure shall be demonstrated by performing an examination of an object or mockup. The examiner conducting the demonstration shall not have been involved in developing the procedure. The completed report forms provide documentation of the demonstration. Qualification of the procedure is only valid when applying the same essential variables recorded during the demonstration. Changes to essential variables require requalification of the procedure. Editorial changes to the procedure, or changes to nonessential variables, do not require requalification of the procedure.

(b) The demonstration of the written procedure may use blind or non-blind certified personnel. Blind performance demonstrations qualify the complete examination system (i.e., the equipment, the written procedure, and the examiner). Non-blind demonstrations only qualify the procedure and the equipment. All recordable indications shall be sized and located. The detection records shall note whether indications are located correctly. Depth, height, and length sizing capabilities are only qualified by a blind performance demonstration.

(c) Demonstrations can be performed by a non-blind demonstration using a few flaws, a demonstration mandated by the referencing Code Section, reiterative blind testing, a combination of multiple small specimen demonstrations; or using a rigorous, statistically based demonstration based on binomial distributions with reduced, one-sided confidence limits. Acceptable demonstration methodologies shall be described in the technical justification for that procedure.

(d) An individual or organization shall be designated as the administrator of the demonstration process. The roles of the administrator include:

(1) reviewing the technical justification;

(2) reviewing the procedure and its scope of applicability;

(3) ensuring that all essential variables are included in the procedure and demonstration;

(4) assembling the test specimens;

(5) grading the demonstrations;

(6) developing the protocol;

(7) maintaining security of the samples; and

(8) maintaining the demonstration records.

For straightforward applications, the administrator may be a department within the owner's organization. For complex demonstrations, or when Code or user requirements dictate, it may be appropriate to use a disinterested third party.

T-1443 EXAMINATION SYSTEM REQUALIFICATION

The original qualification applies only to the system and essential variables described in the technical justification report and the written procedure. If essential variables are changed, requalification is required. Requalification may be accomplished by one of the following means:

(a) The characteristics of the new equipment can be compared to the qualified equipment. If they are essentially identical, the new equipment can be substituted, except when the referencing construction Code invokes more stringent requirements for substituting equipment.

(b) New equipment may be requalified by conducting another complete examination qualification. A hierarchical approach should be used to qualify the new equipment by conducting the demonstration on the most difficult test specimens. Then there is no need to requalify the equipment on the entire set of test specimens.

(c) Modeling may be used to requalify a procedure when proper justification supports such an approach.

T-1450 CONDUCT OF QUALIFICATION DEMONSTRATION

T-1451 PROTOCOL DOCUMENT

A protocol document shall be prepared to ensure continuity and uniformity from qualification-to-qualification. The protocol document forms the basis for third party oversight, and sets the essential variables to be qualified, ensuring portability of the qualification. The protocol document commonly takes the form of a written procedure and associated checklist, documenting the process followed during qualification. This document is developed collectively with the involvement of all the affected parties (i.e., the owner, and, when applicable, the Jurisdiction, AIA, independent third party, examination vendor, or other involved party).

A key element of the protocol document is the Pass/Fail criteria. An alternative evaluation criteria that may be applied is an "achieved level of performance criteria." For this criteria, an examiner demonstrates the technique, including sizing capabilities, and the qualification is based on the detection range the examiner achieves during the demonstration. Examiners qualified under these criteria are permitted to conduct examinations within their qualified capabilities.

T-1452 INDIVIDUAL QUALIFICATION

The performance demonstration requirements found in T-1440 qualify the examination system (i.e. equipment, written procedure, and personnel) as a unit. As an alternative, a two-stage qualification process may also be applied. The first stage of this process involves a performance demonstration to qualify the system procedure/equipment. The procedure/equipment qualification requires several qualified examiners to evaluate the specimen set, with the results meeting predetermined requirements more stringent than personnel pass/fail requirements. After the procedure/equipment has been qualified, individual examiners using the qualified procedure/equipment combination need only to perform a limited performance demonstration.

The principal incentive for adopting this form of test is to reduce costs in personnel qualification of a widely used procedure. The procedure/equipment may be qualified/developed in a non-blind fashion but the personnel shall take blind tests. This two-step process also precludes the possibility of an examiner attempting to pass a demonstration test with inadequate procedures or equipment.

T-1460 CALIBRATION

Calibration of equipment shall be in accordance with the written procedure used to conduct the performance demonstration.

T-1470 EXAMINATION

The performance demonstration shall be conducted in accordance with the written procedure, using the techniques and equipment described in the technical justification. Supplemental information for conducting various modes of performance demonstrations is provided in the following paragraphs.

T-1471 INTERMEDIATE RIGOR DETECTION TEST

The objective of an intermediate rigor performance demonstration test is to reveal inadequate procedures and examiners. Following are typical options for flaws in specimen test sets used for intermediate rigor performance demonstrations:

(a) Specimens should accurately represent the component to be examined to the greatest extent possible, with at least 10 flaws or grading units as a minimum. A POD of 80% with a false call rate less than 20% is required for acceptable performance.

(b) Less than 10 flaws or grading units are used, but they shall be used in a blind fashion. The flaws are reused in an iterative, blind, and random process. This is an economic way to increase the sample set size. Eighty percent of the flaws are required to be detected. The false call rate should be less than 20%.

(c) Between 5 and 15 flaws or grading units are used with at least the same number of unflawed grading units. A POD of 80% with a false call rate less than 20% is required for acceptable performance.

(d) Sample set size shall be sufficient to ensure that most examiners with an unacceptable POD will have difficulty passing the demonstration, while most examiners with an acceptable POD will be able to pass the demonstration.

T-1472 HIGH RIGOR DETECTION TESTS

The following guidelines describe the methodology for constructing POD performance demonstration tests for examination system qualification. In order to construct any of the detection tests mentioned in this appendix, the following information must be assembled:

(a) the type of material and flaws the procedure is supposed to detect

(b) the size of the critical flaw for this application

(c) the minimum acceptable POD that inspection should achieve for critical flaws (Call this POD_{min}.)

(d) the maximum acceptable false call probability that the inspection should display (Call this FCP_{max}.)

(e) the level of confidence that the test is supposed to provide (The most widely applied level of confidence being 95%.)

T-1472.1 Standard Binomial Detection Test. The examiner is subjected to a blind demonstration. The flawed grading units contain critical flaws (i.e., flaws near the critical flaw size) so that a POD calculated from this data estimates the POD for critical flaws. After the examination, the POD and FCP scores are calculated by comparing the number of detections classified as flaws to the number of flawed or blank grading units examined. In other words:

$$\text{POD Score} = \frac{\text{\# of flawed grading units as flaws}}{\text{Total \# of flawed grading units examined}} \quad (1)$$

$$\text{FCP Score} = \frac{\text{\# of blank grading units classified as flaws}}{\text{Total \# of blank grading units examined}} \quad (2)$$

The POD and FCP are supported by tolerance bands called "α bounds" to describe the statistical uncertainty in the test. (In the case of POD a lower α bound is used, while for FCP, an upper α bound is used.) The examiner's score is acceptable if the lower bound on POD score is above POD_{min}, and the upper bound on FCP score is below FCP_{max}.

The α bounds are calculated using standard binomial equations, shown below.

Where:

D = Number of detections recorded
N = Number of grading units that contain flaws (for POD calculations) or that are blank (for FCP calculations)
P_{upper} = upper α bound
P_{lower} = lower α bound

$$\alpha = \beta(P_{lower}; D, N - D + 1] \quad (3)$$

$$\alpha = 1 - \beta(P_{upper}; D + 1, N - D] \quad (4)$$

where $\beta(z; c_1, c_2)$ is a beta distribution with parameters c_1 and c_2. The design of a statistically significant sample set for this test is based on the above binomial equations.

A POD of 95% with a 90% confidence implies that there is a 90% probability that 95% is an underestimate of the true detection probability. In other words, the confidence level, α describes how reliable the qualification test must be. If 10 flaws are in the test, then on the basis of 2 misses, there is a 90% confidence that the true inspection reliability is greater than 55%. If 95% confidence is desired, then the true inspection reliability is greater than 49.3%. If all 10 flaws were detected at a 90% confidence level, then the POD would be 79%. To obtain a 90% POD at a 95% confidence level requires a minimum of 29 flaws out of 29 flaws to be detected.

Table T-1472.1 shows the relationship between smallest number of flaws, confidence level, probability of detection, and misses by calculating the equation above for various scenarios. It can be used to develop the size of the test set. The user is free to select the actual number of flawed and blank locations (i.e., the sample size) employed in the test. The user's choice for sample size will be governed by two competing costs

(a) the cost of constructing test specimens

(b) the cost of failing a "good" examiner

If the user chooses to perform a large test, the confidence bounds associated with the POD scores will be small, so a "good" examiner will have an excellent chance for passing the test. However, if an abbreviated test is given, the confidence bounds will be large, and even a good examiner will frequently fail a test.

In fact, with a binomial test such as this, there is a smallest sample size that can be used. If a sample size smaller than the smallest sample size is used, it is impossible to ever pass the test, because the confidence bounds are so wide. With the smallest sample size, the examiner has to obtain a perfect score (i.e., *POD* = 1, or *FCP* = 0) to pass. The smallest sample size depends upon the detection threshold and the confidence level chosen for the test. For example, as the minimum acceptable POD is set closer to unity, the minimum sample size becomes larger. Table T-1472.1 presents the minimal sample size for various confidence levels, and POD/FCP thresholds.

As one can see from this table, quite a large sample set is required if high detection thresholds are required for the inspection. If exceptionally high detection thresholds are required, the standard binomial test described in this appendix may not be the most efficient testing strategy.

As a general rule, the test should include as many blank as flawed location, but this proportion may be altered depending upon which threshold (POD or FCP) is more stringent.

As developed in this section, the standard binomial test examines POD for one flaw size only, the critical flaw size. It is possible to include more flaw sizes in the test. Each included flaw size would contain the minimum number of flaws required by Table T-1472.1. For example, a 90% detection rate at a 90% confidence level for four different flaw size intervals would require 22 flaws in each size interval if no misses are allowed for a total of 88 flaws.

T-1472.2 Two-Stage Detection Test. The basic component of the two-stage demonstration test is the Standard Binomial Detection Test described in T-1472.1. The two-stage test applies the standard binomial test to personnel qualification, but applies a more stringent test for procedure qualification. The two-stage test is intended to eliminate inadequate procedures from the qualification process, preserving resources. The motivating objective for a two-stage test is to construct the first stage to eliminate a procedure whose pass rate is unacceptably low. (A procedure's pass rate is the proportion of trained examiners that would pass the personnel test when using this procedure.)

A two-stage test is ideally suited for an examination scenario where many examiners will be using a few standardized procedures, which may differ substantially in

Table T-1472.1
Total Number of Samples for a Given Number of Misses at a Specified Confidence Level and POD

Level of Confidence	Number of Misses	Probability of Detection 90%	95%	99%
90%	0	22	45	230
	1	38	77	388
	2	52	105	531
	3	65	132	667
	4	78	158	798
	5	91	184	926
	10	152	306	1,000+
	20	267	538	1,000+
95%	0	29	59	299
	1	46	93	473
	2	61	124	628
	3	76	153	773
	4	89	181	913
	5	103	208	1,000+
	10	167	336	1,000+
	20	286	577	1,000+
99%	0	44	89	458
	1	64	130	662
	2	81	165	838
	3	97	198	1,000+
	4	113	229	1,000+
	5	127	259	1,000+
	10	197	398	1,000+
	20	325	656	1,000+

Table T-1472.2
Required Number of First Stage Examiners vs. Target Pass Rate

Target Pass Rate, R_{pass}	Number of First Stage Examiners, M
50	3
60	4
70	5
80	8
90	15
95	32

performance. If only one procedure is available, or if each examiner applies a separate own customized procedure, two-stage testing is not advantageous.

In order to construct a two-stage detection test, the same information that must be assembled for the standard binomial test is required, with the addition of a target pass rate, R_{pass}, for personnel. The target pass-rate is the pass-rate that the user considers acceptable.

The procedure qualification (1^{st} stage) portion of the test requires that M procedure-trained examiners each pass a standard binomial detection test. The standard binomial detection test, constructed in accordance with T-1472.1, will be used for personnel qualification. The key difference is that more that one examiner is used for procedure qualification. It is important that the procedure test be conducted with examiners that are representative of the field population (and not experts). A "procedure-trained" examiner should be one that has received the standard training required for the procedure.

After the procedure has passed its test, then individual examiners are allowed to be qualified in the second stage, using the same standard binomial test. The binomial test is constructed so that critical flaws are detected with a POD of at least POD_{min} and false calls are no more than FCP_{max} with a level of confidence of α.

The number of examiners (M) used in the first stage is chosen to assure the desired pass-rate at 80% confidence (i.e. the user can be 80% sure that the actual pass-rate will be above the target value). The equation for determining the proper M is:

$$M = \frac{\log(1 - 0.80)}{\log(R_{pass})} \quad (5)$$

Table T-1472.2 provides the M associated with various target pass rates.

The user is completely free to choose the number of examiners (M) employed in the first stage of qualification. As one can see from the above table, the larger that M is made, the more stringent the procedure portion of the test becomes, but the higher the pass-rate becomes on the second stage of the test. In fact, for high M, the user might eliminate the second stage of the test entirely.

T-1472.3 Iterative Detection Test. This detection test is useful when the test specimens are extremely costly or limited. It is constructed in the same manner as the standard binomial test from T-1472.1, however the test presents the applicant with the same set of specimens more than once to obtain the desired sample size.

Less than 10 flaws are used, but they are used in a blind fashion. The flaws are reused in an iterative, blind, and random process. This is an economic way to increase the sample set size. The flawed and unflawed grading units are examined several times until the desired sample size and corresponding confidence level is reached. The specimens must be indistinguishable from each other so that each examination is independent and the test team cannot recognize the specimen or the flaws. The number of unflawed grading units must at least equal or exceed the number of flawed grading units. Table T-1472.1 may be used to determine the flaw sample size, misses, and POD for a given confidence level.

T-1480 EVALUATION

The owner, and, when applicable, the Jurisdiction, AIA, independent third party, examination vendor, or other user shall evaluate the technical justification report, and the results of the performance demonstration submitted by the administrator, to determine the acceptability of the system. The evaluation shall be based upon the criteria established within the protocol document.

T-1490 DOCUMENTATION AND RECORDS

Documentation of the performance demonstration shall include the following:

(a) The technical justification document

(b) NDE procedures, including the essential variables applied

(c) Description of the equipment used, including the calibration records

(d) Description of the specimens used to perform the demonstration

(e) Certification of acceptable completion of the performance demonstration. The certification may be issued separately for the equipment/procedure and the individual.

MANDATORY APPENDIX II
UT PERFORMANCE DEMONSTRATION CRITERIA

II-1410 SCOPE

This Mandatory Appendix provides requirements for three levels of performance demonstration for ultrasonic examination procedures, equipment, and personnel used to detect and size flaws in welds and components for Construction Code applications.

Refer to T-1410 regarding specific requirements of the referencing Code Section.

II-1420 GENERAL

Article 14, T-1410 through T-1490, shall be used in conjunction with this Appendix. Those requirements apply except as modified herein.

Personnel shall be qualified as specified in Article 1, T-120, and the requirements of the level of rigor specified for Article 14 and this Appendix.

Selection of the level of rigor (low, intermediate, or high) shall be in accordance with the referencing Code Section, and, if not specified, shall be the responsibility of the Owner/User.

Each organization shall have a written program that ensures compliance with this Appendix.

Each organization that performs ultrasonic examination shall qualify its procedures, equipment, and personnel in accordance with this Appendix.

Performance demonstration requirements apply to all personnel who detect, record, or interpret indications, or size flaws.

Any procedure qualified in accordance with this Appendix is acceptable.

Alternatively, the requirements of Section XI, Appendix VIII, may be used.

II-1430 EQUIPMENT

II-1434 QUALIFICATION BLOCKS

II-1434.1 Low Level. Qualification blocks shall be fabricated similar to a calibration block in accordance with Article 4, T-434, or Article 5.

II-1434.2 Intermediate Level. Qualification blocks shall be in accordance with T-434.1.2 through T-434.1.6. The procedure shall be demonstrated to perform acceptably on a qualification block (or blocks) having welds, or alternatively, having flaws introduced by other processes that simulate the flaws of interest. The block shall contain a minimum of three axial flaws oriented parallel to the weld's fusion line as follows: (1) one surface flaw on the side of the block representing the component OD surface; (2) one surface flaw on the side of the block representing the component ID surface; and (3) one subsurface flaw.

Qualification block flaws shall be representative of the flaws of concern, such as, for new construction, slag, cracks, or zones of incomplete fusion or penetration, and, for post-construction, flaws representing the degradation mechanisms of concern.

If the inside and outside surfaces are comparable (e.g., no overlay or cladding present, similar weld joint details and welding processes, etc.) and accessible, one surface flaw may represent both the ID and OD surface flaws.

Qualification blocks shall include flaws having a length no longer than the following, with flaw height no more than 25%t or $1/4$ in. (6 mm), whichever is smaller:

(a) For surface flaws, $1/4$ in. (6 mm) in blocks having thickness t up to 4 in. (100 mm)

(b) For subsurface flaws

(1) $1/4$ in. (6 mm) for t up to $3/4$ in. (19 mm)

(2) $1/3t$ for t from $3/4$ in. (19 mm) to $2\,1/4$ in. (57 mm)

(3) $3/4$ in. (19 mm) for t from $2\,1/4$ in. (57 mm) to 4 in. (100 mm)

(c) For blocks over 4 in. (100 mm) thick, the blocks shall include flaws having a size no greater than a flaw acceptable to Table II-1434-1 or Table II-1434-2 for the thickness being qualified. Figure II-1434 identifies dimensioning of surface and subsurface flaws.

II-1434.3 High Level. Qualification test specimens shall be provided representative of the weld to be examined. A sufficient number of test specimens shall be evaluated to effectively estimate sizing error distributions, and determine an accurate probability of detection (POD) for specific degradation mechanisms or flaw types and sizes. The number, size, orientation, type, and location of flaws in the specimens shall be as specified by the referencing Code Section or the Owner/User (if the referencing Code does not address) based on POD and confidence level requirements.

II-1440 APPLICATION REQUIREMENTS

Refer to T-1440.

Table II-1434-1
Flaw Acceptance Criteria for 4-in. to 12-in. Thick Weld

	4 in. ≤ t ≤ 12 in.	
Aspect Ratio, a/ℓ	Surface Flaw, a/t	Subsurface Flaw, a/t
0.00	0.019	0.020
0.05	0.020	0.022
0.10	0.022	0.025
0.15	0.025	0.029
0.20	0.028	0.033
0.25	0.033	0.038
0.30	0.038	0.044
0.35	0.044	0.051
0.40	0.050	0.058
0.45	0.051	0.067
0.50	0.052	0.076

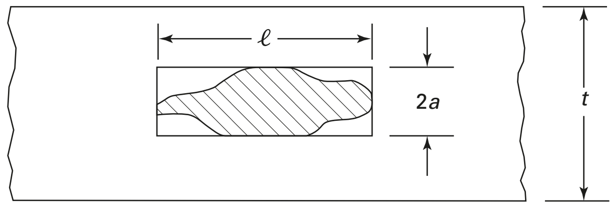
GENERAL NOTES:
(a) t = thickness of the weld excluding any allowable reinforcement. For a buttweld joining two members having different thickness at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet weld shall be included in t.
(b) A subsurface indication shall be considered as a surface flaw if separation of the indication from the nearest surface of the component is equal to or less than half the through thickness dimension of the subsurface indication.

Table II-1434-2
Flaw Acceptance Criteria for Larger Than 12-in. Thick Weld

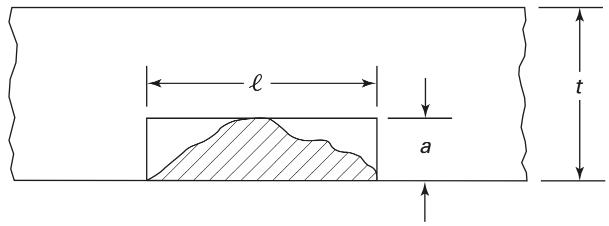
Aspect Ratio, a/ℓ	Surface Flaw, a, in.	Subsurface Flaw, a, in.
0.00	0.228	0.240
0.05	0.240	0.264
0.10	0.264	0.300
0.15	0.300	0.348
0.20	0.336	0.396
0.25	0.396	0.456
0.30	0.456	0.528
0.35	0.528	0.612
0.40	0.612	0.696
0.45	0.618	0.804
0.50	0.624	0.912

GENERAL NOTES:
(a) For intermediate flaw aspect ratio, a/ℓ linear interpolation is permissible.
(b) t = the thickness of the weld excluding any allowable reinforcement. For a buttweld joining two members having different thickness at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet weld shall be included in t.
(c) A subsurface indication shall be considered as a surface flaw if separation of the indication from the nearest surface of the component is equal to or less than half the through thickness dimension of the subsurface indication.

Figure II-1434
Flaw Characterization for Tables II-1434-1 and II-1434-2



(a) Subsurface Flaw



(b) Surface Flaw

II-1450 CONDUCT OF QUALIFICATION DEMONSTRATION

The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability; e.g., material, including thickness dimensions, product form (castings, forgings, plate, pipe), material specification or P-number grouping, heat treatment, and strength limit (if applicable).

The examination procedure shall specify the following essential variables:

(a) instrument or system, including manufacturer, and model or series, of pulser, receiver, and amplifier

(b) search units, including manufacturer, model or series, and the following:

(1) nominal frequency

(2) mode of propagation and nominal inspection angles

(3) number, size, shape, and configuration of active elements and wedges or shoes

(4) immersion or contact

(c) search unit cable, including the following:

(1) type

(2) maximum length

(3) maximum number of connectors

(d) detection and sizing techniques, including the following:

(1) scan pattern and beam direction

(2) maximum scan speed

(3) minimum and maximum pulse repetition rate

(4) minimum sampling rate (automatic recording systems)

(5) extent of scanning and action to be taken for access restrictions

(6) surface from which examination is performed

(e) methods of calibration for both detecting and sizing (e.g., actions required to insure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeatable from examination to examination)

(f) inspection and calibration data to be recorded

(g) method of data recording

(h) recording equipment (e.g., strip chart, analog tape, digitizing) when used

(i) method and criteria for the discrimination of indications (e.g., geometric versus flaw indications and for length and depth sizing of flaws)

(j) surface preparation requirements

The examination procedure shall specify a single value or a range of values for the applicable variables listed.

II-1460 CALIBRATION

Any calibration method may be used provided it is described in the written procedure and the methods of calibration and sizing are repeatable.

II-1470 EXAMINATION

Refer to T-1470.

II-1480 EVALUATION

II-1481 LOW LEVEL

Acceptable performance is defined as detection of reference reflectors specified in the appropriate Article 4, T-434 qualification block. Alternatively, for techniques that do not use amplitude recording levels, acceptable performance is defined as demonstrating that all imaged flaws with recorded lengths, including the maximum allowable flaws, have an indicated length equal to or greater than the actual length of the specified reflectors in the qualification block.

II-1482 INTERMEDIATE LEVEL

Acceptable performance is defined as

(a) detection of flaws in accordance with T-1471 and sizing of flaws (both length and depth) equal to or greater than their actual size; unless specified otherwise by the referencing Code Section, or

(b) meeting Section XI, Appendix VIII requirements

II-1483 HIGH LEVEL

Acceptable performance is defined as meeting either of the following:

(a) T-1472 and T-1480 requirements

(b) Owner/User specified requirements

II-1490 DOCUMENTATION

The organization's performance demonstration program shall specify the documentation that shall be maintained as qualification records. Documentation shall include identification of personnel, NDE procedures, and equipment used during qualification, and results of the performance demonstration. Specimens shall be documented only where appropriate/applicable. For instance, specimens used in a blind or "PDI" qualification would not be documented.

ARTICLE 15
ALTERNATING CURRENT FIELD MEASUREMENT TECHNIQUE (ACFMT)

T-1510 SCOPE

(a) This Article describes the technique to be used when examining welds for linear type discontinuities $^{1}/_{4}$ in. (6 mm) and greater in length utilizing the Alternating Current Field Measurement Technique (ACFMT).

(b) When specified by the referencing Code Section, the ACFMT examination technique in this Article shall be used together with Article 1, General Requirements.

(c) In general, this Article is in conformance with SE-2261, Standard Practice for Examination of Welds Using the Alternating Current Field Measurement Technique.

T-1520 GENERAL

The ACFMT method may be applied to detect cracks and other linear discontinuities on or near the surfaces of welds in metallic materials. The sensitivity is greatest for surface discontinuities and rapidly diminishes with increasing depth below the surface. In principle, this technique involves the induction of an AC magnetic field in the material surface by a magnetic yoke contained in a hand held probe, which in turn causes a uniform alternating current to flow in the material. The depth of the penetration of this current varies with material type and field frequency. Surface, or near surface, discontinuities interrupt or disturb the flow of the current creating changes in the resulting surface magnetic fields which are detected by sensor coils in the probe.

T-1521 SUPPLEMENTAL REQUIREMENTS

ACFMT examinations of some types of welds (e.g., dissimilar, austenitic and duplex, etc.) may not be possible or may result in a larger flaw (i.e, depth) detection threshold than carbon and low alloy steel ferritic-type weld examinations because of the wide variations in magnetic permeability between the weld, heat-affected zone, and plate material. It is necessary in these cases to modify and/or supplement the provisions of this Article in accordance with T-150(a). Additional items, which are necessary, are production weld mock-ups with reference notches or other discontinuities machined adjacent to, as well as within, the weld deposit.

T-1522 WRITTEN PROCEDURE REQUIREMENTS

T-1522.1 Requirements. ACFMT shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-1522. The written procedure shall establish a single value, or range of values, for each requirement.

T-1522.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-1522 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as an nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1530 EQUIPMENT

T-1531 INSTRUMENT

ACFMT instrument and software shall be capable of operating over a range of frequencies of from 1 to 50 kHz. The display shall contain individual time or distance-based plots of the x compound of the magnetic field B_x, parallel to the probe travel, z component of the magnetic field B_z, perpendicular to the examination surface, and a combined B_x and B_z plot (i.e., butterfly display).

T-1532 PROBES

The nominal frequency shall be 5 kHz unless variables, such as materials, surface condition, or coatings require the use of other frequencies.

T-1533 CALIBRATION BLOCKS

T-1533.1 General.

T-1533.1.1 Block Material. The material from which the block is fabricated shall be of the same product form and material specification, or equivalent P-number grouping, of the materials being examined.

T-1533.1.2 Weld Material. Blocks fabricated out of P-3 group materials or higher shall contain a representative weld of the same A-number grouping as the weld being examined.

Table T-1522
Requirements of an ACFMT Examination Procedure

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Instrument (Model and Serial No.)	X	...
Probes (Model and Serial No.)	X	...
Directions and extent of scanning	X	...
Method for sizing (length and depth) indications, when required	X	...
Coating	X	...
Coating thickness (increase only)	X	...
Personnel performance qualification requirements, when required	X	...
Surface preparation technique	...	X
Personnel qualification requirements	...	X

T-1533.1.3 Notches. Known depth and length notches shall be used to verify that the system is functioning properly.

T-1533.1.4 Quality. Prior to fabrication, the block material shall be completely examined with an ACFMT unit to assure it is free of indications that could interfere with the verification process.

T-1533.1.5 Heat Treatment. The block shall receive at least the minimum tempering treatment required by the material specification for the type and grade.

T-1533.1.6 Residual Magnetism. The block shall be checked for residual magnetism and, if necessary, demagnetized.

T-1533.2 Calibration Block. The calibration block configuration and notches shall be as shown in Figure T-1533. Notches shall be machined at the toe (e.g., heat-affected zone) and in the weld for blocks containing welds.

T-1540 MISCELLANEOUS REQUIREMENTS

T-1541 SURFACE CONDITIONING

(a) Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged condition. However, surface preparation by grinding may mask an indication and should be avoided when possible or kept to a minimum.

(b) Prior to ACFMT examination, the surface to be examined and all adjacent areas within 1 in. (25 mm) shall be free of dirt, mill scale, welding flux, oil, magnetic coatings, or other extraneous matter that could interfere with the examination.

(c) Cleaning may be accomplished by any method that does not adversely affect the part or the examination.

(d) If nonmagnetic coatings are left on the part in the area to be examined, it shall be demonstrated to show that indications can be detected through the maximum coating thickness present.

T-1542 DEMAGNETIZATION

Residual magnetic fields can interfere with the ACFMT induced field and may produce false indications; therefore, ACFMT should be performed prior to a magnetic particle examination (MT). If ACFMT is performed after MT, the surface shall be demagnetized if any strong residual fields exist.

T-1543 IDENTIFICATION OF WELD EXAMINATION AREAS

(a) Weld Location. Weld locations and their identification shall be recorded on a weld map or in an identification plan.

(b) Marking. If welds are to be permanently marked, low stress stamps and/or vibrating tools may be used, unless prohibited by the referencing Code Section.

(c) Reference System. Each weld shall be located and identified by a system of reference points. The system shall permit identification of each weld and designation of regular intervals along the length of the weld.

T-1560 CALIBRATION

T-1561 GENERAL REQUIREMENTS

T-1561.1 ACFMT System. Calibrations shall include the complete ACFMT system (e.g., instrument, software, computer, probe, and cable) and shall be performed prior to use of the system.

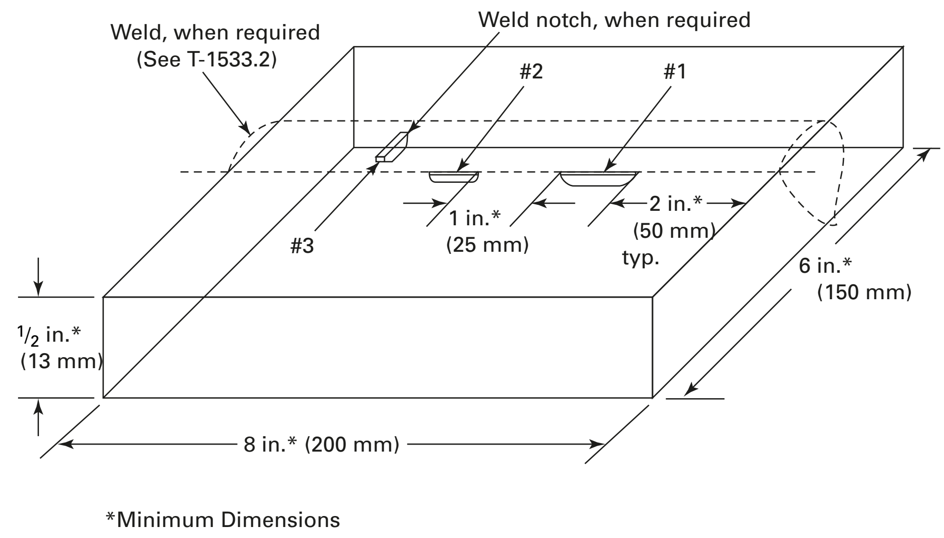
T-1561.2 Probes. The same probe to be used during the examination shall be used for calibration.

T-1561.3 Instrument Settings. Any instrument setting which affects the response from the reference notches shall be at the same setting for calibration, verification checks, and the examination.

T-1562 CALIBRATION

T-1562.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibration.

Figure T-1533
ACFMT Calibration Block



Elliptical Notch ID	Length, in. (mm)	Depth, in. (mm)	Width, in. (mm)
1	2 (50)	0.2 (5)	
2	0.25 (6)	0.1 (2.5)	0.02 (0.5) max.
3	0.25 (6)	0.1 (2.5)	

GENERAL NOTES:
(a) The tolerance on notch depth shall be ±0.01 in. (±0.2 mm).
(b) The tolerance on notch #1 length shall be ±0.04 in. (±1 mm).
(c) The tolerance on notches #2 and #3 length shall be ±0.01 in. (±0.2 mm).
(d) Notch shape shall be elliptical.
(e) Notch #3 only required when block contains a weld.

T-1562.2 Probe. The selected probe, and cable extensions if utilized, shall be connected to the instrument and the manufacturers' standard probe file loaded.

T-1562.3 Instrument Display Scan Speed. The display scan speed shall be set at the maximum rate to be used during the examination.

T-1562.4 Probe Scanning Rate. The instrument shall be calibrated by passing the probe over the notches in the calibration block and noting the responses. The nose of the probe shall be orientated parallel to the notch length and shall maintain contact with surface being examined. The probe scan rate shall not exceed that which displays a butterfly loop from the notch #1 of 50% (±10%) of full scale height and 175% (±20%) of full scale width and that also can readily detect a signal response from the smaller notch.

T-1562.5 Probe Sensitivity. When the requirements of T-1562.4 cannot be met, the probe sensitivity shall be adjusted, a different probe file loaded, or another probe selected and the notches again scanned per T-1562.4.

T-1563 PERFORMANCE CONFIRMATION

T-1563.1 System Changes. When any part of the examination system is changed, a verification check shall be made on the calibration block to verify that the settings satisfy the requirements of T-1562.2.

T-1563.2 Periodic Checks. A verification check shall be made at the finish of each examination or series of similar examinations, and when examination personnel are changed. The response from notch #1 shall not have changed by more than 10% in either the B_x or B_z response. When the sensitivity has changed by more than 10%, all data since the last valid verification check shall be marked void or deleted and the area covered by the voided data shall be reexamined.

T-1570 EXAMINATION

T-1571 GENERAL EXAMINATION REQUIREMENTS

T-1571.1 Rate of Probe Movement. The maximum instrument scan speed and probe scanning rate shall be as determined in T-1562.4.

T-1571.2 Probe Contact. The probe shall be kept in contact with the examination surface during scanning.

T-1571.3 Direction of Field. At least two separate examinations shall be performed on each area, unless otherwise specified by the referencing Code Section. During the second examination, the probe shall be positioned perpendicular to that used during the first examination.

T-1572 EXAMINATION COVERAGE

The weld to be scanned shall be examined by placing the probe at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld. The probe shall then be moved parallel to and along the weld toe. A second longitudinal scan shall be performed along the opposite toe of the weld. These two scans shall then be repeated per T-1571.3. Unless demonstrated otherwise, if the width of the weld is wider than $^3/_4$ in. (19 mm), an additional set of scans shall be performed along the centerline of the weld.

T-1573 OVERLAP

The overlap between successive probe incremental scans shall be 1 in. (25 mm) minimum.

T-1574 INTERPRETATION

The interpretation shall identify if an indication is false, nonrelevant, or relevant. False and nonrelevant indications shall be proven false or nonrelevant. Interpretation shall be carried out to identify the location and extent of the discontinuity and whether it is linear or nonlinear. Determination of discontinuity size (length and depth) is not required unless specified by the referencing Code Section.

T-1580 EVALUATION

All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

T-1590 DOCUMENTATION

T-1591 RECORDING INDICATION

T-1591.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-1591.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the extent and location shall be recorded.

T-1592 EXAMINATION RECORD

For each examination, the following information shall be recorded:

(a) procedure identification and revision;

(b) ACFMT instrument identification (including manufacturers' serial number);

(c) software identification and revision;

(d) probe identification (including manufacturers' serial number and frequency);

(e) probe file identification and revision;

(f) calibration block identification;

(g) identification and location of weld or surface examined;

(h) map or record of rejectable indications detected or areas cleared;

(i) areas of restricted access or inaccessible welds;

(j) examination personnel identity and, when required by the referencing Code Section, qualification level; and

(k) date of examination.

T-1593 REPORT

A report of the examination shall be made. The report shall include those records indicated in T-1591 and T-1592. The report shall be filed and maintained in accordance with the referencing Code Section.

ARTICLE 16
MAGNETIC FLUX LEAKAGE (MFL) EXAMINATION

T-1610 SCOPE

This Article describes the Magnetic Flux Leakage (MFL) examination method requirements applicable for performing MFL examinations on coated and uncoated ferromagnetic materials from one surface. MFL is used in the examination of tube and piping to find unwelded areas of longitudinal weld joints. It is also used as a post construction examination method to evaluate the condition of plate materials, such as storage tank floors, and piping for corrosion or other forms of degradation. Other imperfections that may be detected are cracks, seams, incomplete fusion, incomplete penetration, dents, laps, and nonmetallic inclusions, etc.

When this Article is specified by a referencing Code Section, the MFL method described in this Article shall be used together with Article 1, General Requirements.

T-1620 GENERAL

T-1621 PERSONNEL QUALIFICATION REQUIREMENTS

The user of this Article shall be responsible for documented training, qualification, and certification of personnel performing MFL examination. Personnel performing supplemental examinations, such as ultrasonic (UT) examinations, shall be qualified in accordance with the referencing Code Section.

T-1622 EQUIPMENT QUALIFICATION REQUIREMENTS

The equipment operation shall be demonstrated by successfully completing the unit verification and function tests outlined as follows.

T-1622.1 Reference Specimen. All MFL examinations shall have a reference plate or pipe section to ensure the equipment is performing in accordance with the manufacturer's specifications prior to use. The reference specimen for plate shall consist of a plate that is made from a material of the same nominal thickness, product form, and composition as the component to be examined. The plate specimen shall have notches or other discontinuities machined into the bottom of the plate, as shown in Figure T-1622.1.1. The reference specimen for pipe or tubing shall consist of a pipe or tube that is made from a material of the same nominal pipe or tube sizes, product form, and composition as the component to be examined. The pipe or tube specimen shall have notch discontinuities machined into the inside and outside surfaces as shown in Figure T-1622.1.2. The depths and widths of the artificial discontinuities should be similar to the sizes and physical characteristics of discontinuities to be detected. If nonmagnetic coatings or temporary coverings will be present during the examination, the reference specimen shall be coated or covered with the nonmagnetic coatings or covers representative of the maximum thickness that will be encountered during the examination.

T-1622.2 System Verification and Function Checks. The manufacturer's verification procedure shall be conducted initially to ensure that the system is functioning as designed. The functional check shall be made by scanning the reference plate over the range of scanning speeds to be utilized during the examination. Equipment settings shall be documented.

T-1622.3 Performance Confirmation. A functional check shall be conducted at the beginning and end of each examination, every 8 hr, or when equipment has malfunctioned and been repaired. If it is determined that the equipment is not functioning properly, needed adjustments shall be made and all areas examined since the last performance check shall be reexamined.

T-1623 WRITTEN PROCEDURE REQUIREMENTS

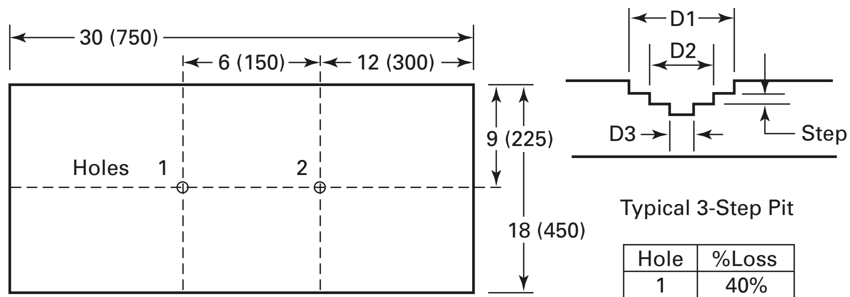
T-1623.1 Requirements. MFL examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-1623. The written procedure shall establish a single value, or range of values, for each requirement.

The procedure shall address, as a minimum, the identification of imperfections, reference materials used to set up equipment, location and mapping of imperfections, and the extent of coverage. The procedure shall address the field strength of the magnets, the functioning of the sensors, and the operation of the signal-processing unit. Other examination methods that will be used to supplement the MFL examination shall be identified in the procedure.

T-1623.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-1623 identified as an essential variable shall require requalification of the written procedure by demonstration. A change in a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or

Figure T-1622.1.1
Reference Plate Dimensions

Plate Thickness	Hole Number	Number of Steps	Step Size	Diameter D1	Diameter D2	Diameter D3	Diameter D4	Diameter D5
$^{1}/_{4}$ (6)	1	3	.032 (0.8)	.47 (12)	.32 (8)	.12 (3)		
	2	4	.032 (0.8)	.62 (16)	.47 (12)	.32 (8)	.12 (3)	
$^{5}/_{16}$ (8)	1	4	.032 (0.8)	.62 (16)	.47 (12)	.32 (8)	.16 (4)	
	2	5	.032 (0.8)	.78 (20)	.62 (16)	.47 (12)	.32 (8)	.16 (4)
$^{3}/_{8}$ (10)	1	4	.039 (1)	.78 (20)	.59 (15)	.39 (10)	.2 (5)	
	2	5	.039 (1)	.96 (24)	.78 (20)	.59 (15)	.39 (10)	.2 (5)



Hole	%Loss
1	40%
2	50%

GENERAL NOTE: Dimensions of references are in in. (mm).

nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1630 EQUIPMENT

The equipment shall consist of magnets, sensor or sensor array, and related electronic circuitry. A reference indicator, such as a ruled scale or linear array of illuminated light-emitting diodes, should be used to provide a means for identifying the approximate lateral position of indications. The equipment may be designed for manual scanning or may be motor driven. Software may be incorporated to assist in detection and characterization of discontinuities.

T-1640 REQUIREMENTS

(a) The surface shall be cleaned of all loose scale and debris that could interfere with the examination and movement of the scanner. The surface should be sufficiently flat to minimize excessive changes in lift-off and vibration. Alternate techniques will be required to handle variables exceeding those specified in the procedure.

(b) Cleaning may be accomplished using high-pressure water blast or by sandblasting. If the material is coated and the coating is not removed, it shall be demonstrated that the MFL equipment can detect the specified imperfections through the maximum thickness of the temporary sheet or coating.

(c) If a temporary sheet or coating is applied between the scanner and plate to provide a smooth surface, for example, on a heavily pitted surface, it shall be demonstrated that the equipment can find the specified imperfections through the maximum thickness of the temporary sheet or coating.

T-1650 CALIBRATION

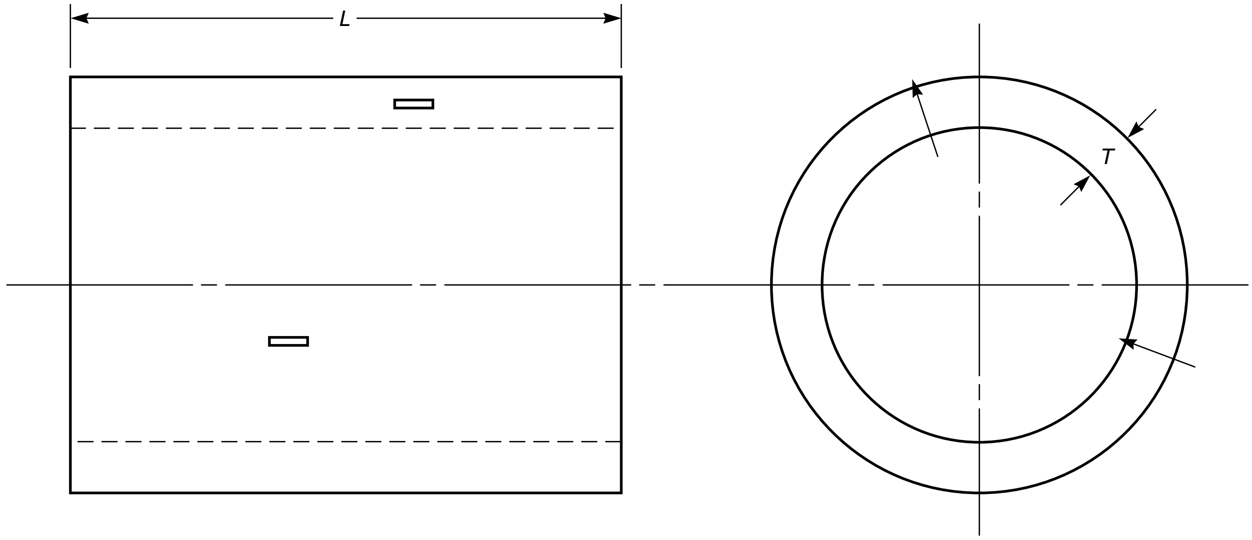
The MFL equipment shall be recalibrated annually and whenever the equipment is subjected to major damage following required repairs. If equipment has not been in use for 1 year or more, calibration shall be done prior to first use.

T-1660 EXAMINATION

(a) Areas to be examined shall be scanned in accordance with a written procedure. Each pass of the sensing unit shall be overlapped in accordance with the written procedure.

(b) The unit shall be scanned manually or by a motor-driven system. Other examination methods may be used to provide coverage in areas not accessible to MFL

Figure T-1622.1.2
Reference Pipe or Tube Dimensions



Typical Block Dimensions

Minimum length L 8 in. (200 mm) or 8T, whichever is greater
Full circumference

Specific Notch Dimensions

Length L – 1 in. (25 mm) maximum
Depth D – 10% T with tolerance (+10% – 20%) of depth
Width – 0.010 in. (0.25 mm) maximum
Location – not closer than 3T from any block edge or other notch in axial direction
Minimum 90 deg from adjacent notch(es)

examinations, in accordance with the written procedure. Typical examples of inaccessible areas in storage tanks are lap welds and corner welds adjacent to the shell or other obstructions, such as roof columns and sumps.

(c) Imperfections detected with MFL exceeding the acceptance standard signal shall be confirmed by supplemental examination(s) or be rejected. Supplemental examination shall be performed in accordance with written procedures.

(d) Where detection of linear imperfections is required, an additional scan shall be performed in a direction approximately perpendicular to the initial scanning direction.

T-1670 EVALUATION

All indications shall be evaluated in accordance with the referencing Code Section.

T-1680 DOCUMENTATION

A report of the examination shall contain the following information:

(a) plate material specification, nominal wall thickness, pipe diameter, as applicable;

(b) description, such as drawing/sketches, documenting areas examined, and/or areas inaccessible;

(c) identification of the procedure used for the examination;

(d) system detection sensitivity (minimum size of imperfections detectable);

(e) location, depth, and type of all imperfections that meet or exceed the reporting criteria;

(f) examination personnel identity and, when required by referencing Code Section, qualification level;

(g) model and serial number of equipment utilized for the examination, including supplemental equipment;

(h) date and time of examination;

(i) date and time of performance verification checks; and

(j) supplemental methods utilized and reference to associated reports.

Table T-1623
Requirements of an MFL Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Equipment manufacturer/model	X	...
Sensor type: manufacturer and model	X	...
Scanning speed/speed range	X	...
Overlap	X	...
Lift-off	X	...
Material examined	X	...
Material thickness range and dimensions	X	...
Reference specimen and calibration materials	X	...
Software	X	...
Evaluation of indications	X	...
Surface conditioning	X	...
Coating/sheet thickness	X	...
Performance demonstration requirements, when required	X	...
Scanning technique (remote control/ manual)	...	X
Scanning equipment/fixtures	...	X
Personnel qualification requirements	...	X

ARTICLE 17
REMOTE FIELD TESTING (RFT) EXAMINATION METHOD

(19) ## T-1710 SCOPE

(a) This Article contains the techniques and requirements for Remote Field Testing (RFT) examination.

(b) The requirements of Article 1, General Requirements, apply when a referencing Code Section requires RFT examination.

(c) Definition of terms for RFT examinations appear in Article 1, Mandatory Appendix I, I-121.5, ET — Electromagnetic (Eddy Current).

(d) Article 32, SE-2096, Standard Practice for In Situ Examination of Ferromagnetic Heat Exchanger Tubes Using Remote Field Testing, shall be used as referenced in this Article.

T-1720 GENERAL

T-1721 WRITTEN PROCEDURE REQUIREMENTS

T-1721.1 Requirements. RFT examinations shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Table T-1721. The written procedure shall establish a single value, or range of values, for each requirement.

T-1721.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-1721 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1722 PERSONNEL REQUIREMENTS

The user of this Article shall be responsible for assigning qualified personnel to perform RFT examination to the requirements of this Article. Recommendations for training and qualifying RFT system operators are described in SE-2096. Personnel performing RFT examinations shall be qualified in accordance with requirements of the referencing Code Section.

T-1730 EQUIPMENT

RFT equipment capable of operating in the absolute or differential mode (or both modes) as specified in the written procedure, together with suitable probes and a device for recording the RFT data in a format suitable for evaluation and archival storage are all essential parts of the system. The means of displaying signals shall be on a Voltage Plane (also known as an Impedance Plane, a Voltage Plane Polar Plot, and an X-Y Display). Equipment and fixtures for moving probes through tubes and for scanning may be used.

T-1750 TECHNIQUE

(a) Single or multiple frequency techniques are permitted for this examination.

(b) Following the selection of the examination frequency(ies) and the completion of the setup using a reference standard, the probe shall be pulled through the tubes to be examined at a speed that shall be uniform and appropriate to the examination frequency, digital sampling rate, and required sensitivity to flaws. This rate of scanning shall be used to perform the examination.

Table T-1721
Requirements of an RFT Examination Procedure

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Frequency(ies)	X	...
Mode (Different/Absolute)	X	...
Minimum fill factor	X	...
Probe type	X	...
Equipment manufacturer/model	X	...
Scanning speed	X	...
Identity of artificial flaw reference	X	...
Tube material, size, and grade	X	...
Data analysis technique	X	...
Procedure qualifications, when specified	X	...
Personnel qualifications	...	X
Scanning equipment/fixtures	...	X
Tube surface preparation	...	X
Data recording equipment	...	X
Tube numbering	...	X
Report format	...	X

T-1760 CALIBRATION

T-1761 INSTRUMENT CALIBRATION

RFT instrumentation shall be recalibrated annually and whenever the equipment is subjected to damage and/or after any major repair. When equipment has not been in use for a year or more, calibration shall be performed prior to first use. A tag or other form of documentation shall be attached to the RFT instrument with date of calibration and calibration due date shown.

(19) T-1762 SYSTEM PREPARATION

(a) The RFT system is set up for the examination using artificial flaws fabricated in a reference tube. The reference standard shall be in accordance with SE-2096, Fig. 4, and para. 10.5 of that document. The reference standard shall include a tube support plate fabricated in accordance with SE-2096, para. 10.6. When it is required to detect and size small volume flaws, such as corrosion pits, a second reference tube, such as the example shown in Figure T-1762, shall be used to demonstrate adequate sensitivity. Pit depth and size selection shall be determined by the application. Pit depth tolerance shall be +0/−10%. Hole diameter tolerance shall be ±10%. The spacing of the artificial flaws shall be suitable for the coil spacing on the RFT probe to ensure that flaws or tube ends are not near the exciter(s) and detector(s) at the same time.

Tubes used as reference standards shall be of the same nominal dimensions and material type as the tubes to be examined.

(b) Where either the exact material type or dimensional matches are not available, an alternative tube may be used. A demonstration of the equivalency of the alternate reference is required. An example of demonstrating normalized response is when one of the following responses from the reference standard and the nominal tube are equal:

(1) the amplitude and angular position of a support plate indication on the voltage plane

(2) the angular difference between a support plate indication and the tube exit indication on the voltage plane

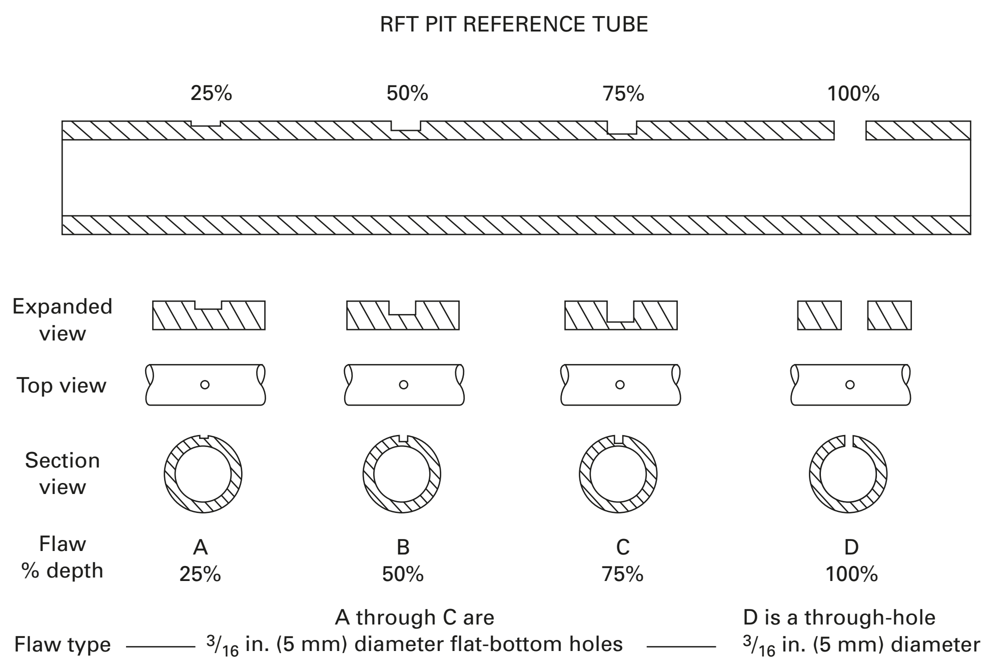
(3) the absolute phase response

T-1763 SYSTEM SETUP AND CALIBRATION

T-1763.1 Differential Channels.

(a) The phase rotation of the base frequency (F1) shall be adjusted so that the signal from the through-wall hole (TWH) appears approximately along the Y (vertical) axis and that the signal from the tube support plate (TSP) lies in the upper left-hand and lower right-hand quadrants. When properly adjusted, the differential signals should be displayed on a voltage plane display, such as those shown in Figures T-1763.1(a) and T-1763.1(b).

Figure T-1762
Pit Reference Tube (Typical)



NOTE: not to scale

Figure T-1763.1(a)
Voltage Plane Display of Differential Channel Response for Through-Wall Hole (Through-Hole Signal) and 20% Groove Showing Preferred Angular Relationship

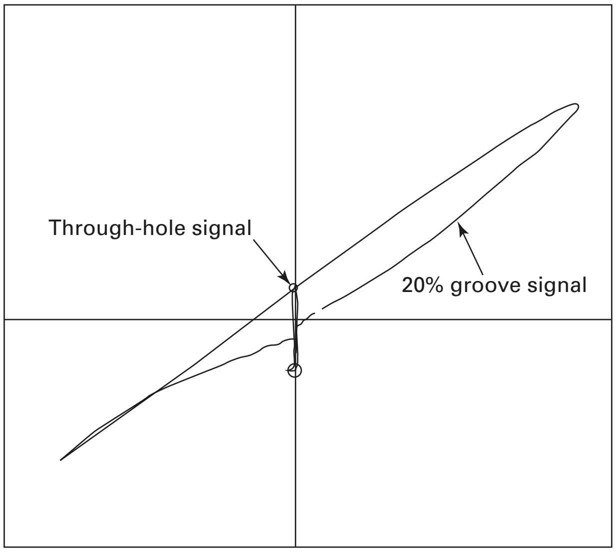
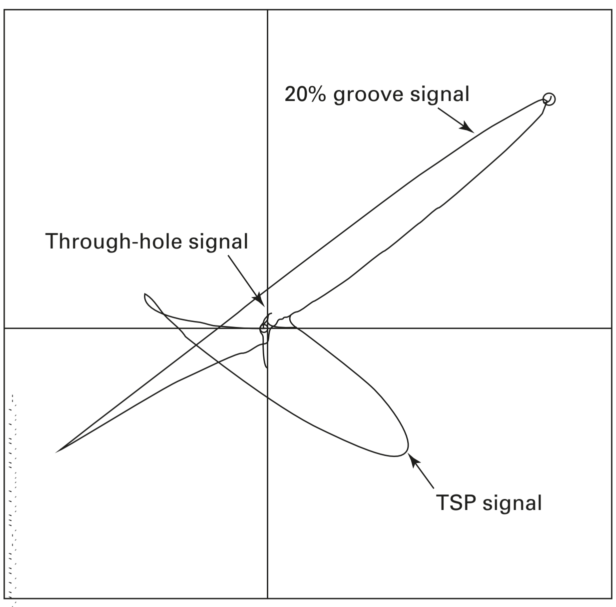


Figure T-1763.1(b)
Voltage Plane Display of Differential Channel Response for the Tube Support Plate (TSP), 20% Groove, and Through-Wall Hole (Through-Hole Signal)



(b) The signal response for the through-wall hole reference flaw shall be generated when pulling the probe past the hole such that the initial response is downward followed by an upward motion and then back to the null point on the voltage plane.

(c) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of approximately 50% full screen height from the through-wall hole.

(d) The response from the 20% wear groove in the reference tube should be at approximately 150 deg (as measured clockwise from the negative X-axis). See Figure T-1763.1(a). The angular difference between the TWH response and the 20% flaw response shall be 60 deg ±10 deg. Alternate initial response angles representing artificial flaws may be used, providing the difference between the TWH response and the 20% groove response meets this criteria.

T-1763.2 Absolute Channels.

(a) The signal responses for absolute channels are set up using a procedure similar to that used to set up the differential channels using the Voltage Plane display. Absolute signals will appear as half the extent of differential signals.

(b) Voltage Plane Polar Plot displays may also be used for setting up the absolute probe technique using the following procedure:

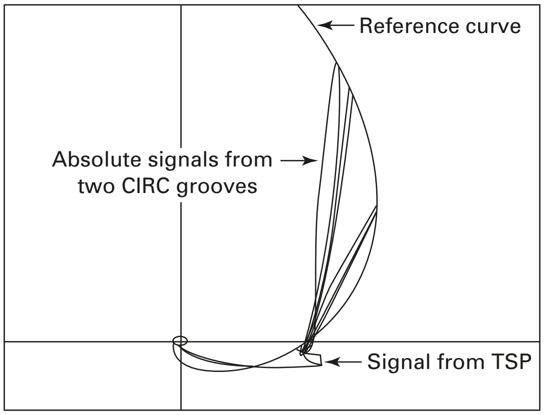
(1) Adjust the frequency(ies) and phase of the signal from the through hole in the reference standard so that it originates at 1, 0 on the polar plot display and develops by going upward and to the left at an angle between 20 deg and 120 deg measured clockwise from the X axis. The TSP signal will lie approximately parallel to the X axis.

(2) If a reference curve is used, the signals from the two 20% grooves in the reference standard should peak close to the reference curve. If they do not peak close to the reference curve, the test frequency and/or probe drive shall be adjusted until they do.

(3) Signals from flaws that are evenly displaced around the circumference of the tube, such as "general wall loss," will typically follow the reference curve. Signals from imperfections that are predominantly on one side of the tube will appear inside the reference curve. Signals from magnetic permeability variations will appear outside the reference curve. Figure T-1763.2 illustrates the Voltage Plane Polar Plot display with the signals from two circumferential grooves, a tube support plate, and the reference curve.

T-1763.3 Dual Exciter and Array Probes. Dual exciter and array probes may be used provided system performance is demonstrated by use of the reference standard. Displays used may vary from system to system.

Figure T-1763.2
Reference Curve and the Absolute Channel Signal Response From Two Circumferential Grooves and a Tube Support Plate



T-1764 AUXILIARY FREQUENCY(IES) CALIBRATION PROCEDURE

(a) Auxiliary frequencies may be used to examine tubes. They may be multiples (harmonics) of the base frequency or may be independent of the base frequency.

(b) Auxiliary frequencies may be "mixed" with the base frequency to produce an output signal that suppresses unwanted variable responses, such as those from the tube support plates.

(c) When "mixed" signals are used for flaw evaluation, they shall demonstrate sensitivity to reference standard artifical flaw with suppression of the unwanted signal. For example, the unwanted signal may be the tube support plate signal. Auxiliary frequency response and mixed signal response to the unwanted signal shall be part of the calibration record.

(d) The base frequency and auxiliary frequency(ies) response shall be recorded simultaneously.

T-1765 CALIBRATION CONFIRMATION

(a) Calibration of the system hardware shall be confirmed in accordance with requirements of the referencing Code Section. When not specified in the referencing Code Section, analog elements of the system shall be calibrated annually or prior to first use.

(b) Calibration shall include the complete RFT examination system. Any change of the probe, extension cables, RFT instrument, computer, or other recording instruments shall require recalibration of the system, and recalibration shall be noted on the report.

(c) Should the system be found to be out of calibration during the examination, it shall be recalibrated. The recalibration shall be noted on the report. All tubes examined since the last valid calibration shall be reexamined.

T-1766 CORRELATION OF SIGNALS TO ESTIMATE DEPTH OF FLAWS

The "phase angle analysis" method or the "phase lag and log-amplitude analysis" method shall be used to estimate the depth of flaws. In both cases the size (amplitude) of the signal is related to flaw surface area, and the phase angle is related to the flaw depth. The method used shall be fully documented in the examination records and the relationship between flaw dimensions and signals shall be described. One or both methods may be used for flaw depth and size estimation.

T-1766.1 Phase Angle Method. A relationship of signal phase angles to reference flaw depths shall be developed for the examination being performed.

T-1766.2 Phase-Lag Method. A relationship of phase lag angle and log-amplitude of signals from the reference standard flaws shall be developed for the examination being performed.

T-1770 EXAMINATION

T-1771 GENERAL

Data shall be recorded as the probe traverses the tube. The data may be gathered in a "timed" mode or a "distance encoded" mode. The axial location of discontinuities shall be estimated by reference to known features or by encoder measurements.

T-1772 PROBE SPEED

The probe speed shall be dependent on the base frequency and sample rate and shall be no faster than the speed required to obtain a clear signal from the reference standard through-wall hole, without any measurable phase shift or amplitude change of the signal.

T-1780 EVALUATION

The analysis and evaluation of examination data shall be made in accordance with the referencing Code Section.

T-1790 DOCUMENTATION

A report of the examination shall be generated. The report shall include, at a minimum, the following information:

(a) owner, location, type, serial number, and identification of component examined;

(b) size, wall thickness, material type, and configuration of installed tubes;

(c) tube numbering system;

(d) extent of examination or tubes examined and length of tubes scanned;

(e) personnel performing the examination;

(1) qualification level when required by the referencing Code Section

(f) date of examination;
(g) models, types, and serial numbers of components of the RFT system;
(h) probe model/type and extension length;
(i) all relevant instrument settings;
(j) serial number(s) of reference tube(s);
(k) procedure used — identification and revision;
(l) acceptance criteria used;
(m) identify tubes or specific regions where limited sensitivity and other areas of reduced sensitivity or other problems;
(n) results of the examination and related sketches or maps of the examined area; and
(o) complementary tests used to further investigate or confirm test results.

T-1793 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

ARTICLE 18
ACOUSTIC PULSE REFLECTOMETRY (APR) EXAMINATION

T-1810 SCOPE

When specified by the referencing Code Section, the acoustic pulse reflectometry (APR) method described in this Article shall be used together with Article 1, General Requirements. Definition of terms used in this Article may be found in Article 1, Mandatory Appendix I, I-121.10, (APR — Acoustic Pulse Reflectometry).

T-1820 GENERAL

The APR examination method is used for the detection of discontinuities open to or on the internal surfaces of tubes and piping. Typical types of discontinuities that can be detected by this method are cracks, corrosion pits, through-wall holes, wall loss, and blockages.

In principle, this method involves sending a short duration pulse of an acoustic wave through the tube or pipe and then analyzing any returned reflection signals from discontinuities or blockages of the tube or pipe against the signal baseline from a discontinuity free tube or pipe. The initial phase (positive or negative) of the returned reflection of the acoustic wave and its shape are characteristic of the type and size of discontinuity that is detected and can be used to estimate its size.

T-1821 WRITTEN PROCEDURE REQUIREMENTS

T-1821.1 Requirements. APR examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-1821. The written procedure shall establish a single value, or range of values, for each requirement.

T-1821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-1821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1830 EQUIPMENT

T-1831 INSTRUMENTATION

APR equipment includes a pulser, an adapter for sealing the probe to the tube or pipe end, and a device for recording the APR data. Equipment shall include a monitor to display signals in an unrectified voltage versus distance format.

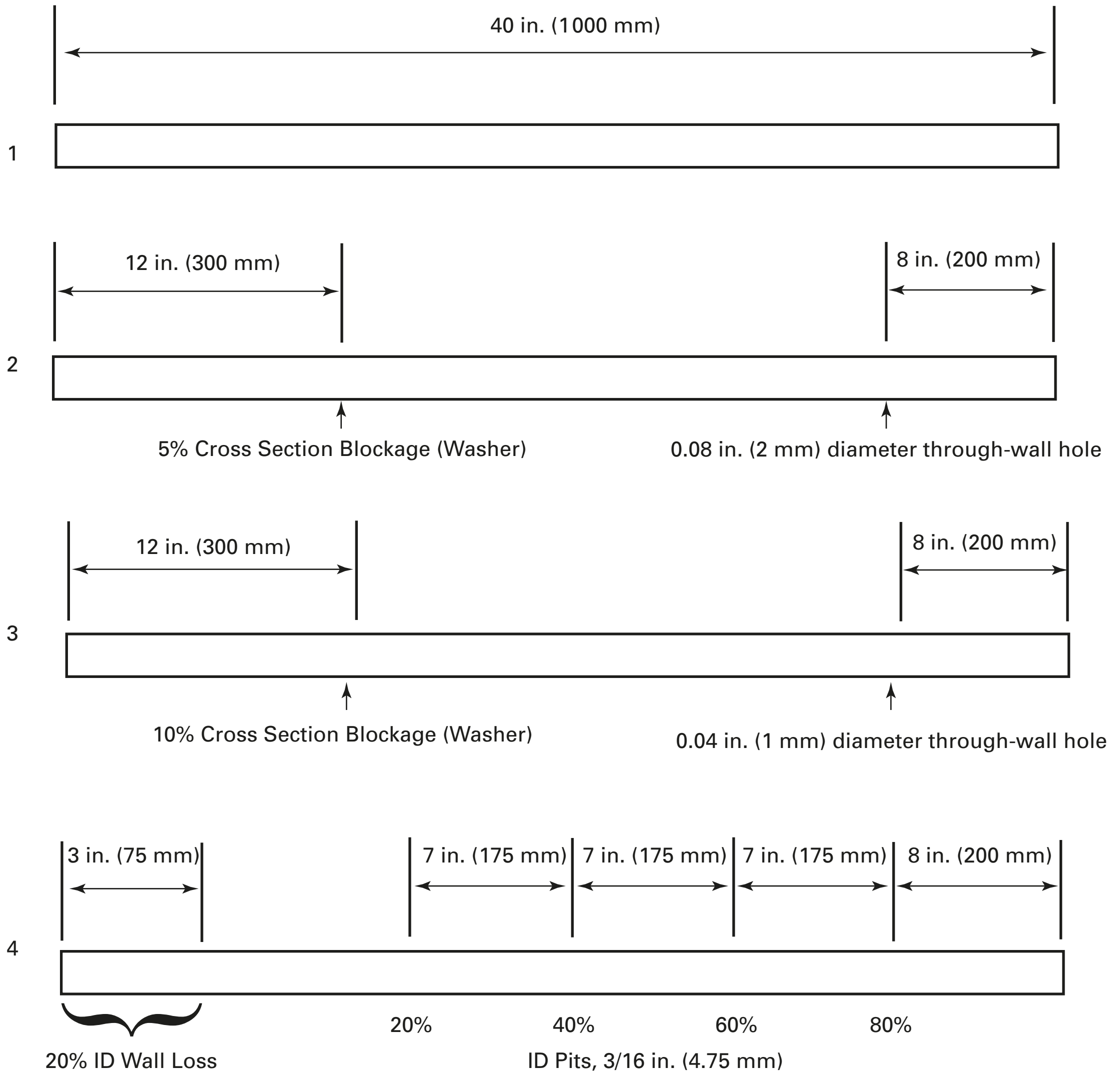
T-1832 REFERENCE SPECIMEN

The reference specimens shall be in accordance with Figure T-1832. When it is required to detect and size small volume flaws, such as corrosion pits, reference tube number 4, Figure T-1832, shall be used. The following formulas shall be used to determine the size of washer or segment of a circle fastened to the inside diameter of the tube or pipe for different amounts of blockage:

Table T-1821
Requirements of an Acoustic Pulse Reflectometry Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Adaptor type	X	...
Probe type	X	...
Temperature of tube or pipe	X	...
Equipment (manufacturer/model)	X	...
Pulse signal intensity	X	...
Tube or pipe material nominal diameter and wall thickness	X	...
Data analysis technique	X	...
Tube surface preparation and cleaning	X	...
Procedure qualifications when specified	X	...
Flaw type evaluation methodology	X	...
Flaw sizing methodology	X	...
Personnel qualifications	...	X
Data recording equipment	...	X
Tube numbering	...	X
Data format	...	X

Figure T-1832
Reference Specimens



GENERAL NOTES:
(a) Pit depth tolerance shall be ±10%.
(b) Hole diameter tolerance shall be ±10%.
(c) The spacing of artificial reflectors shall provide separate signals without interference.
(d) Blockage and wall loss tolerance shall be ±10%.

(a) For Washer Reflectors. As an example for a tube with an inside diameter of 1 in. (25 mm), if it is desired to have a 10% blockage:

$$\text{I.D. area of washer} = \frac{(\text{washer inside diameter})^2}{(\text{tube diameter})^2}$$

For 10% blockage, I.D. area of washer = 0.9

For 1 in. (25 mm) inside diameter tube:

$$0.9 = \frac{(\text{washer inside diameter})^2}{(1\text{ in.})^2} = \frac{(\text{washer inside diameter})^2}{(25\text{ mm})^2}$$

(Washer inside diameter)^2 = 0.9 in.^{2} = 563 mm^2

Washer inside diameter = $\sqrt{0.9\text{ in.}^2}$ or $\sqrt{563\text{ mm}^2}$

Washer inside diameter = 0.95 in. or 23.73 mm

(b) For Segment of a Circle Reflector. For a 5% blockage, the height of the segment shall be 9.74% of the tube or pipe inside diameter. For a 10% blockage, the height of the segment shall be 15.65% of the tube or pipe inside diameter. The area of a segment blockage shall be calculated using the following equation:

$$A = \left[R^2 \cos^{-1}\frac{(R-h)}{R} = (R-h)\sqrt{2Rh - h^2}\right]$$

where

A = area of segment, in.^{2} (mm^2)
$\cos^{-1}$ = angle is in radians
h = height of segment, in. (mm)
R = inside-diameter radius of tube, in. (mm)

T-1840 MISCELLANEOUS REQUIREMENTS

T-1841 TUBE OR PIPE PRECLEANING

Precleaning shall be performed prior to the examination. Precleaning may be accomplished using detergents, organic solvents, air, water, or other means to clean the inside surfaces. The pipe or tube shall be clean enough so that the acoustic wave can travel to the specified length of the tube or pipe to be examined. The pipe or tube walls shall be dried and free of any standing water prior to examination.

T-1850 PRIOR TO THE EXAMINATION

(a) The appropriate adapter shall be selected to ensure an adequate seal between the probe and the tubes or pipes.

(b) Setup measurements shall be performed to optimize the signal intensity per T-1863.

T-1860 CALIBRATION

T-1861 INSTRUMENT CALIBRATION

APR instrumentation shall be calibrated annually, when the accuracy of the system is in question, and whenever the equipment is subjected to damage and/or after any repair. When the instrument has not been in use for 1 yr or more, calibration shall be performed prior to first use. Analog and digital elements of the system shall be calibrated at least annually or prior to first use.

T-1862 SYSTEM PREPARATION

The APR system is to be set up for the examination using the reference reflectors in the reference tube bundle shown in Figure T-1832 unless the referencing Code Section requires the same nominal diameter and wall thickness pipes or tubes in the reference specimen as the tubes or pipes being examined.

T-1863 SYSTEM SETUP (19)

(a) Verification of proper system function (functional test) shall be performed using the reference specimens specified in T-1832 prior to examination of the tubing or piping. Test measurements shall be carried out on the tubes or pipe and the signal intensity shall be adjusted to optimize the signal-to-noise ratio (SNR). Test measurements shall be carried out on a random tube out of the bundle to be inspected. The signal intensity shall be adjusted to achieve the best SNR. This may be done manually or through an automated procedure that runs through a range of intensity settings. To calculate SNR, two values shall be determined: signal intensity and noise intensity. Signal intensity shall be determined from the recording of the outgoing pulse; noise intensity shall be determined from the signals recorded after the pulse and the strong reflections from the end of the tube have decreased in intensity below the remaining noise levels. Signal-to-noise ratio shall be at least 80 dB.

(b) Tube or pipe cleanliness shall be verified by examining at least 30 tubes and applying a statistical calculation to determine the level of noise in the signals caused by reflections from any residues. This noise level shall be used as a threshold for detectable flaws. Any flaws whose expected peak heights fall below this threshold shall be deemed undetectable in the examined tubing or piping. If this threshold falls below the minimum detectability specified by the referencing Code Section, the tubes or pipes shall be recleaned and reexamined. If the minimum limits cannot be achieved, the examination may be performed but for informational purposes only, not for Code compliance.

T-1864 FUNCTIONAL TEST

(a) A functional test shall be performed to include the complete APR examination system. Any change of the probe, extension cables, APR instrument, data recording,

or analysis equipment shall require a functional test of the system, and the functional test shall be noted on the report.

(b) The functional test shall include verification of correct sizing of the reference specimen's reflectors as follows:

(1) The reflections from reference blockages/through-wall holes in reference tubes 2 and 3 shall be recorded and compared to reference values supplied by the manufacturer, with respect to the reflection's phases, heights, and widths, within 10%,

(2) If sizing of pits is required, the reflections from the reference pits in tube 4 shall be recorded and compared to reference values supplied by the manufacturer, with respect to the reflection's phases, heights, and widths, within 10%,

(3) If sizing of wall loss is required, the reflections from reference wall loss in reference tube 4 shall be recorded and compared to reference values supplied by the manufacturer, with respect to the reflection's phases, heights, and widths, within 10%.

(c) As a minimum, a functional test shall be conducted at the completion of each examination or series of similar examinations using the same reference specimens used originally. Functional tests should be conducted frequently for large numbers of tubes or pipes.

(d) If the signal intensity from the artificial flaws in the reference bundle has changed by more than 2 dB of the original intensity, a new functional test shall be performed. The APR unit shall be repaired or recalibrated before the new functional test is performed. All tubing or piping examined since the last valid functional test shall be reexamined.

T-1865 ANALYSIS OF SIGNALS TO DETERMINE FLAW TYPE AND ESTIMATE FLAW SIZE

An indication's initial signal polarity shall be used to determine the type of flaw and its size. A leading positive peak followed by a negative peak indicates blockage, whereas a leading negative peak followed by a positive peak indicates wall loss. An isolated asymmetric negative peak indicates a hole (See Figures T-1865.1 and T-1865.2). Sizing of flaws shall be accomplished by comparing leading peak heights of each type of flaw to a theoretical calculation simulating a range of flaw sizes. This calculation shall take into account attenuation of the acoustic pulse as it propagates down the tube or pipe. Graphic indications on the monitor displaying the acquired signals may be used to aid this process. The axial extent of the indication's pulse length shall be used to determine the length of the flaw. Flaw sizing below the thresholds determined by the procedure to assess cleanliness described in T-1841 shall not be attempted. In the case where attenuation makes it impossible to detect distant flaws, tubes or pipes shall be examined from both ends if accessible. The method used shall be fully documented in the examination records and the relationship between flaw dimensions and signals shall be described.

T-1870 EXAMINATION

Each tube or pipe shall be examined in accordance with the written procedure and the data shall be recorded for the full length of each tube or pipe. The axial location of indications shall be calculated based on a reflection's arrival time and the speed of sound, adjusted for temperature.

T-1880 EVALUATION

All indications shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-1890 DOCUMENTATION

For each examination, the following information shall be recorded:

(a) owner, location, type, serial number, and identification of component examined

(b) size, wall thickness, material type, and configuration of installed tubes/pipes

(c) tube/pipe numbering system

(d) extent of examination or tubes/pipes examined and length of tubes/pipes scanned

(e) personnel performing the examination

(f) qualification level when required by the referencing Code Section

(g) date of examination

(h) models, types, and serial numbers of components of the APR system

(i) adapter model/type and extension length

(j) instrument settings

(k) signal-to-noise ratio

(l) pulse signal intensity

(m) procedure used — identification and revision

(n) acceptance criteria used

(o) results of the examination and related sketches or maps of the examined area

(p) complementary examinations used to further investigate or confirm examination results

(q) serial number of artificial flaw reference standard

(r) identification of tubes or pipes where reflections limit or prevent the specified length being fully examined

T-1891 RECORDING INDICATIONS

All indications shall be recorded as specified by the referencing Code Section.

T-1892 EXAMINATION RECORDS

All examination records shall be retained as specified in the referencing Code Section.

T-1893 STORAGE MEDIA

Storage media for computerized scanning data and viewing software shall be capable of securely storing and retrieving data for the time period specified by the referencing Code Section.

Figure T-1865.1
Signal Analysis From Various Types of Discontinuities

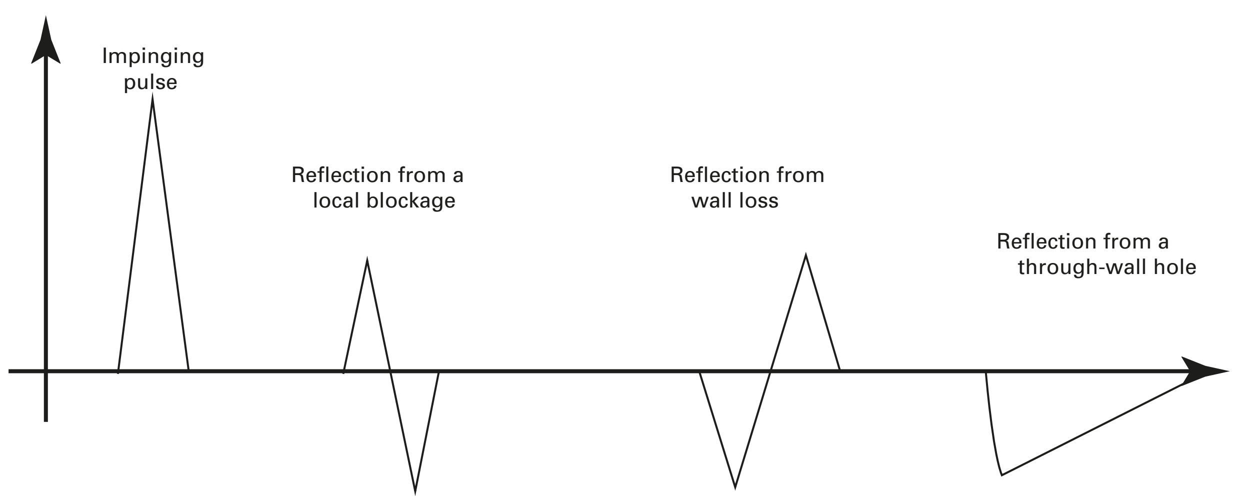
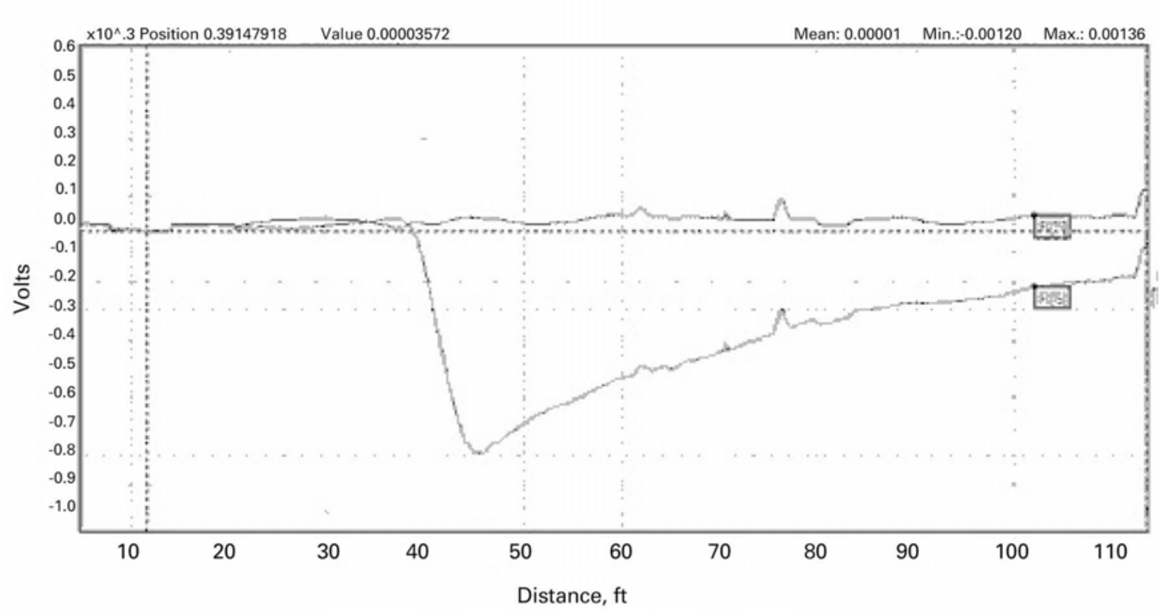


Figure T-1865.2
Reflection From a Through-Wall Hole



ARTICLE 19
GUIDED WAVE EXAMINATION METHOD FOR PIPING

T-1910 SCOPE

When specified by the referencing Code Section, the guided wave examination (GWT) described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Article 1, Mandatory Appendix I, I-121.11

T-1920 GENERAL

(a) GWT, as described in the Article, is for the examination of basic metal piping configurations to find areas of changing pipe wall cross section over a long distance from one sensor location. GWT is used to detect service induced anomalies (typically corrosion, erosion) either internal or external.

(b) GWT systems consist of a sensor that is mounted onto the pipe being examined and connected to an electronics system that sends excitation pulses to the sensor so that guided waves are generated in the pipe under examination. The guided wave propagation characteristics are controlled by the geometry of the component being examined and can have very complex propagation modes.

(c) Once generated, the wave travels in the pipe wall and is scattered by changes in the wall thickness caused by corrosion, welds, or other wall thickness anomalies. The GWT sensor electronics allows these waves to be detected and recorded for analysis. Most GWT systems operate in the pulse-echo mode, as well as in the pitch-catch mode, which is very similar to the conventional ultrasonics electronic systems. The basics of the GWT system operations are discussed in Nonmandatory Appendix A.

T-1921 WRITTEN PROCEDURE REQUIREMENTS

T-1921.1 Requirements. Guided wave examination shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Table T-1921.1. The written procedure shall establish a single value, or range of values, for each requirement.

T-1921.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table T-1921.1 identified as an *essential variable* from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential variable* from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

T-1922 PERSONNEL QUALIFICATION

The personnel performing guided wave examination shall be qualified to recognized GWT standards such as ASTM E2775 and ASTM E2929. Training and experience in the usage of the equipment is required, the recommendations from equipment manufacturers on training requirements for different applications shall be followed, whenever possible, and described in the employer's written practice (see T-120).

T-1930 EQUIPMENT

T-1931 INSTRUMENTATION REQUIREMENTS

The pulse-echo mode or pitch-catch mode technique shall be used. The electronics system used for processing and analyzing the signals shall be capable of distinguishing the guided wave mode(s) used for the specific detection system. The instrument shall also include a device for displaying and recording the data.

T-1932 SENSORS

(a) Sensors in the frequency range of 10 kHz to 250 kHz shall be used and may be either a single continuous ring or a set of individual sensors formed into a ring so that axially symmetric waves are generated. Other frequencies may be used for specialized examination as prescribed by the GWT procedure.

(b) The number and positioning of the sensors in the axial and circumferential directions of the pipe shall ensure that there is separation in each direction of the individual guided wave modes.

T-1950 WAVE MODES

One or more of the following guided wave modes in the pipe wall shall be used:

(a) torsional mode waves
(b) flexural mode waves
(c) longitudinal mode waves

Table T-1921.1
Requirements of a GWT Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Pipe configurations to be examined, including diameters, thickness dimensions and base material product form	X	...
The locations from which the examination shall be performed (for example, isometric drawing of pipe layout notating branches, tees, supports, and other geometric features)	X	...
Identification of length of pipe to be examined	...	X
Evaluation sensitivity (call level)	X	...
Minimum acceptable performance (signal-to-noise ratio)	X	...
Transducer type(s) and guided wave instrument	X	...
Couplant or mechanical force, if used	X	...
Test frequencies	X	...
Test technique (pulse-echo or pitch-catch)	X	...
Number and position of sensors	X	...
Surface from which the examination shall be performed	X	...
Calibration technique(s)	X	...
Direction and distance of examination	X	...
Method for assessing indications	X	...
Personnel performance requirements, when specified	X	...
Personnel qualification requirements	X	...
Computer software version	X	...

T-1951 MISCELLANEOUS REQUIREMENTS

T-1951.1 Selection of the Sensor Position (SP). [SP is also known as test position (TP).]

(a) The SP shall be located on a section of straight pipe.

(b) The distance between the SP and the area to be examined shall be equal to or greater than the total length of the combined dead zone and near field (as described in the specification provided by the sensor manufacturer).

(c) The SP shall be selected such that there are no structural features within the near field (as described in the specification provided by the sensor manufacturer).

(d) When selecting a SP between two structural features, such as girth welds, the SP shall be placed toward one of the structural features such that it is not midway between the two features.

(e) The SP shall be selected so that there is overlap in diagnostic length with that of adjacent GWT examinations.

T-1951.2 Surface Preparation of the SP. Insulation or coating material shall be removed, if necessary to permit sensor placement.

(a) The pipe surface shall be free of loose material at the sensor position. Loose scale and paint shall be removed except where safety precludes it or it is not allowed. Well-adhered paint or epoxy layers up to 0.02 in. (0.5 mm) thick do not need to be removed.

(b) A visual examination shall be carried out of the pipe surface at the sensor position after preparation. If there is general corrosion pitting and metal loss areas on the outer surface of the pipe, the sensor(s) shall be moved, if possible, to a location where the O.D. surface is smooth.

T-1951.3 Thickness Measurement at the SP. The pipe wall thickness shall be measured within the area on which the sensor will be mounted. A minimum of four readings shall be recorded at roughly equally spaced positions around the pipe circumference. If the pipe is horizontally installed, these positions shall include the top and the bottom of the pipe. If any measured value is less than 90% of the nominal wall thickness, then the sensor(s) shall be moved, if possible, to a location where the pipe wall thickness is at least 90% of nominal.

T-1951.4 Temperature Measurement at the SP. If the temperature of the pipe is greater than ambient temperature, the pipe surface temperature shall be measured to ensure it does not exceed the limit recommended by the sensor manufacturer.

T-1960 CALIBRATION

T-1961 INSTRUMENT CALIBRATION

(a) Equipment shall be calibrated in accordance to the equipment manufacturer's procedure at intervals not to exceed 1 yr, or prior to first use thereafter, and whenever the equipment has been damaged or repaired. As a minimum, the following operating characteristics shall be validated:

(1) power supply voltage

(2) transmitter frequency and amplitude

(3) DAC and/or TCG linearity

(b) The equipment shall have a valid calibration certificate from the manufacturer or the organization that performed the calibration.

T-1962 SYSTEM CALIBRATION

(a) A system calibration shall be conducted on the pipe being examined. It shall consist of the following stages:

(1) Determining the signal-to-noise ratio (SNR) of a response from a weld within the examination area. The SNR from the weld shall be greater than 2.

(2) Verifying the correct functionality of the sensor.

(3) Calibrating the range of the instrument based upon known distances between welds and/or other features such as branches or clamps.

(b) The system calibration shall be conducted prior to examination, at the completion of examination or series of similar examinations, and whenever any part of the examination system is changed.

T-1963 DISTANCE–AMPLITUDE CORRECTION (DAC) OR TIME-CORRECTED GAIN (TCG)

(a) When the pipe section in the test range has an appropriate reflector such as a flange or an open end, it shall be used for calibration as a 100% cross-sectional change. If a flange or open end is unavailable, one or more girth welds that are in that test range shall be used for calibration. For piping with nominal wall thickness of 0.28 in. to 0.5 in. (7 mm to 13 mm), the reflection from a girth weld may be approximated to be a 20% cross-sectional change. For piping with nominal wall outside the range of 0.28 in. to 0.5 in. (7 mm to 13 mm), the weld cap shall be measured when accessible in order to more accurately estimate cross-sectional change. If not accessible, the reflection from a girth weld may be approximated to be a 20% cross-sectional change.

(b) The attenuation of the guided waves with distance along the pipe shall be determined in order to set DAC or TCG for the reference amplitude. This shall be determined using the indications from two or more girth welds.

(c) The rate of attenuation represented by the reference amplitude DAC or TCG shall be calculated and if the rate of attenuation is greater than 0.3 dB/ft (1 dB/m) in any part of the test range, it is necessary to modify and/or supplement the provisions of this Article in accordance with T-150(a).

T-1964 DETECTION THRESHOLD

The detection threshold shall be set to 6 dB above the background noise level on the A-scan trace at all points along the test range.

T-1965 CALL LEVEL

The call level shall be identified in the GWT written procedure. It is usually set to be equivalent to 5% of the pipe wall cross section.

T-1970 EXAMINATION

T-1971 EXAMINATION COVERAGE

(a) An examination shall be performed using one or more of the guided wave modes required by T-1950 in order to locate any pipe wall cross-sectional changes.

(b) The maximum permissible examination length shall be determined by the attenuation of the signal as it travels along the pipe, indicated by the distance–amplitude correction (DAC) or time-compensated gain (TCG) as described in T-1963, the detection threshold as described in T-1964, and the call level as described in T-1965. The length of the pipe that can be examined is limited to the distance along the pipe for which the call level lies above the detection threshold. Examination is not allowed beyond the permissible examination range.

T-1980 EVALUATION

T-1981 GENERAL

(a) It is recognized that not all reflections indicate discontinuities since certain pipe features produce indications, including girth welds, pipe supports, clamps, branches, and welded attachments, such as lugs. Indications are also produced by multiple reflections between reflectors present in the pipeline. Depth and circumferential and axial extent of the flaw affect the guided wave reflection. The primary factor influencing the reflection is the cross-sectional change (CSC).

(b) The axial length of the discontinuities also influences their reflectivity. At least three examination frequencies (e.g., 30 kHz, 60 kHz, and 100 kHz, or as recommended by the equipment manufacturer) shall be used to identify discontinuities that are small in CSC or have long axial extent with gradually varying CSC.

(c) The position of visible features shall be correlated with the indications in the guided wave trace such as welds, pipe supports, tee and branches, elbows, and flanges.

T-1982 EVALUATION LEVEL

All indications greater than the call level shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria of the referencing Code Section or as documented in the written procedure.

T-1990 DOCUMENTATION

T-1992 EXAMINATION RECORDS

For each GWT examination, the following information shall be recorded:

(a) procedure ID and revision

(b) identification of pipeline examined

(c) description of the part of pipe examined or location of unexamined areas

(d) product inside the pipe

(e) nominal pipe wall thickness and wall thickness measurements at the SP

(f) couplant used, brand name or type

(g) examination conditions, including the examination surface(s) and any variations during the examination

(h) instrument identification (including manufacturer's serial number)

(i) sensor(s) identification (including serial number, frequency, and size)

(j) computer software version

(k) examination technique (i.e., pulse-echo or pitch-catch) used

(l) guided wave mode and frequencies used

(m) number and position(s) of the sensor(s), relative to a known reference

(n) instrument reference level gain and settings used for analysis (e.g., to establish a DAC or TCG as described in T-1963)

(o) detection threshold (T-1964) and call level (T-1965)

(p) schematic indication of identified features (welds, flanges, supports, etc.)

(q) listing of the axial locations where pipe wall cross-sectional changes were identified and if possible circumferential extent

(r) indication maximum amplitude, and location of all rejectable indications

(s) name/identity and, when required by the referencing Code Section, qualification level of the examiner

(t) date of the examination

(u) any special procedures (identification and revision) that have been necessary for prior examinations, such as for parts of the pipeline where there is high attenuation

(v) storage media used for storing the report

NONMANDATORY APPENDIX A
OPERATION OF GWT SYSTEMS

A-1910 SCOPE

This Appendix provides general information regarding the operation of guided wave examination systems.

A-1920 GENERAL

There are two basic types of GWT sensors, namely the piezoelectric and the magnetostrictive. The piezoelectric sensor consists of materials that produce material displacement when excited with an electric pulse thus creating a mechanical wave. The material properties determine the characteristics of the mechanical wave generated. The magnetostrictive sensor consist of a ferromagnetic material which has a residual or impressed biased magnetic field and is excited by a time-varying magnetic field usually applied by an excitation coil. This process generates a mechanical wave. The characteristics of the generated mechanical wave depend on the relationship between the biasing magnetic field and time-varying magnetic field.

As the guided wave propagates in the pipe wall, changes in the cross section of the pipe scatter or reflect the guided wave. While many wave modes are possible, most systems are specifically engineered to generate a single-guided wave mode in the pipe to simplify data analysis. The wave mode is selected to best obtain the desired measurement objective. Typically a mode or mode/frequency combination is chosen that has a constant velocity over the frequency range of operation, such that the signal shape remains constant regardless of propagation distance; this allows the axial location down the length of pipe to be determined simply from the arrival time of the signal reflected by the change in pipe wall cross section returning to the sensor. Three wave mode types are most often used for GWT: longitudinal, torsional, and flexural. Generally, a symmetric mode can be used to detect an anomaly in the direction of propagation whereas an antisymmetric mode can be used to better characterize the anomaly. Most GW modes interact with liquid or product in a pipeline; however, the torsional mode has the least interaction with the product and thus can propagate longer distances. Therefore, the torsional mode is often used for pipe examination. However, any mode may be used if deployed properly.

The GWT sensor is placed around the pipe once the surface has been cleaned (thick coatings need to be removed), so that it will couple to the surface. The GWT sensor can be pulsed causing low-frequency sound to travel longitudinally down the pipe in both directions. The control of the generation and reception of the chosen wave modes is achieved by the design of the sensor and the signal. Furthermore, the design of the sensor allows the waves travelling in each direction to be processed separately, thus enabling separate examination in the upstream and downstream directions from the location of the sensor.

The setup most often used is pulse echo, in which the same sensor transmits and then receives signals. Using specialized electronics, all GWT systems have the ability to control which direction the wave is sent.

In the pulse-echo setup, the GWT sensor sends out a high-level pulse that saturates the receiver circuitry for a period of time. The receiver circuitry must then settle before being able to receive low-amplitude echoes. This short time corresponds to a short region on either side of the sensor that cannot be examined and is referred to as the dead zone. This is identical in concept to the dead zone in conventional pulse-echo UT.

Various pipe features reflect sound at different levels. For example, the sound travelling along the length of the pipe can be reflected up to 100% by a flange, whereas welds typically reflect about 20% of the magnitude because welds often represent only a modest change of pipe wall cross section.

Welds, fittings, clamps, in-casing centering cradles, spacers, and support shoes have characteristic signals. The location of the welds and other construction features can be verified from drawings and used to "field verify" the equipment range of detection at a specified signal-to-noise ratio.

Currently, the GWT process can confirm that the examined section of a pipeline is free from significant wall loss, usually on the order of 3% to 5% of the pipe wall cross section. GWT may be sufficiently sensitive to detect any defects that could cause the pipe segment to rupture. This method is especially useful when pipe is inaccessible or difficult to expose because it is under a crossing or inside a casing. However, GWT cannot detect pinhole leaks.

Figure A-1920 shows the concept of the pulse-echo technique used for long-range guided wave examination. The chosen wave mode is generated by the sensor; this then propagates along the pipe, and is partially reflected at any location where there is a change of the cross section of the pipe. Such locations include benign features such as girth welds, but also flaws such as patches of corrosion. The reflected signals return to the sensor where they are recorded. The figure shows the generation of the mode, and then its reflection from a symmetric feature and from a nonsymmetric feature.

In the example shown in Figure A-1920, the GWT sensor produces a guided wave packet that moves down the pipe toward the weld. The weld reflects part of the wave while most of the wave moves past the weld toward the defect. The defect reflects part of the wave back toward the sensor. The reflected part of the wave is dependent upon the cross-sectional area of the defect. Thus the guided wave is partially transmitted and reflected at each change of pipe wall cross section. The reflected signal from a symmetric feature is itself symmetric, and only the incident symmetric mode is reflected back. The reflected signal from a nonsymmetric feature contains both symmetric and nonsymmetric flexural components.

The flexural wave is caused by lack of symmetry of the feature. The received flexural wave echo contains additional information, enabling the user to better characterize the feature causing the echo; careful identification of these signals can be used to minimize false calls. The phase of the received signal can also be used to differentiate flaw signals from weld signals.

A-1921 CALL LEVEL

The call level is identified in the GWT written procedure. The call level is set to a proportion of the reference amplitude, and therefore it represents a threshold of a particular reflection coefficient. This may be used to set a sensitivity threshold according to defect size. If using DAC for the reference amplitude, then a DAC with the same slope is set up for the call level. If using TCG, then the call level is a constant value for all positions along the examination length. The amplitude of the call level is recorded, in dB, relative to the DAC or TCG level. The examination is considered invalid at any location where the call level lies below the detection threshold.

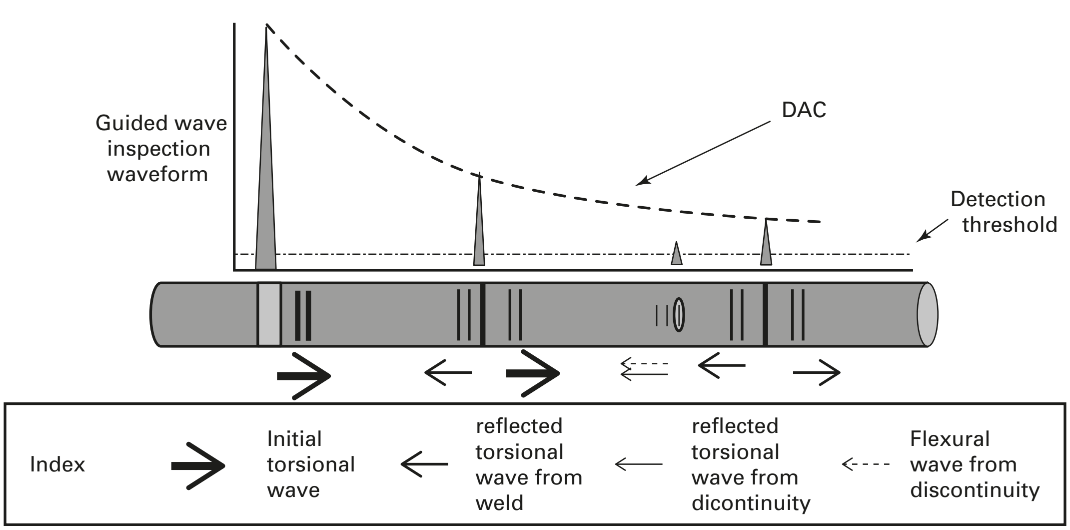
A-1922 EFFECT OF PIPE GEOMETRY ON EXAMINATION RANGE

Pipe fittings such as flanges, tees and branches, supports, and bends affect the guided wave propagation as described in the following subsections.

A-1922.1 Flanges. Flanges are a 100% break in the continuous metal path for guided wave propagation, so that no guided waves will be transmitted across the flanged joint. Therefore, a flange break represents the end of the guided wave examination.

A-1922.2 Tees and Branches. A guided wave will not propagate past a tee, where the pipe under examination terminates at an intersection with another pipe. For this reason, the location of a tee represents the end of the guided wave examination. Guided waves can propagate beyond branch connections, where another pipe taps into the pipe under examination. However, the branch can reflect a significant amount of the guided wave energy as well as distort the energy that propagates beyond the branch if the branch is large relative to the pipe being examined. For this reason, GWT is not performed past a branch if the diameter of the branch is more than half of the diameter of the pipe under examination.

Figure A-1920
Illustration of the Guided Wave Examination Procedure



A-1922.3 Supports.

(a) Contact Supports. Contact supports may cause a small guided wave echo due to local stiffness change. If the area under support is the target of the examination, then examinations are carried out over a range of frequencies.

(b) Welded Supports. Welded supports may cause a large guided wave echo and distort the signals that occur after it. If the area under support is the target of the examination, then examinations are carried out utilizing a range of frequencies.

(c) Clamped Supports. Clamped supports may cause large guided wave echoes and distort the signals that occur after it if the contact between the pipe and the support is metal-to-metal and the support is tightly clamped. If the area under support is the target of the examination, then examinations are carried out over a range of frequencies.

A-1922.4 Bends.

(a) Guided waves propagate smoothly past pulled bends. Tight bends [elbows with bend radius of 3*D* (where *D* is defined as the nominal pipe diameter or less)] cause distortion of the guided wave and, when possible, a new scan should be performed after each elbow fitting. When this is not possible, evaluation of data after the elbow fitting is only performed when indications from expected structural features can be identified beyond the elbow fitting.

(b) Recommendations from the equipment manufacturers should be considered when interpreting signals in or past an elbow. Note that there is likely to be an increased level of background noise beyond a bend, which will decrease the achievable sensitivity. Testing is not performed past a second elbow.

A-1923 EFFECT OF PIPE COATING

Coatings that have low density such as mineral wool and are not well adhered to the pipe surface have little or no effect on the examination range. When the pipe is protected with viscoelastic coating or lining, this causes attenuation of the energy and reduced examination range. When the pipe is embedded in a high density material (sand, clay, concrete, etc.), energy leakage occurs, which causes a significant reduction in examination range. Viscous liquids within piping can also cause loss of energy of the guided waves, no matter which kind of wave modes are deployed.

A-1924 EFFECT OF GENERAL CORROSION ON EXAMINATION RANGE

In general, the wave propagation distance in bare, above-ground pipe can be up to 600 ft (193 m) in length. However, coating such as bitumen and wax greatly increase the attenuation of the guided wave reducing the propagation distance.

If the pipe is generally corroded, the scattering from the small changes in the pipe cross section will cause attenuation of the propagating energy and a reduction in the examination range. The presence of generalized corrosion can be implicitly inferred from the increased attenuation of the signal. If general corrosion is severe enough to cause attenuation greater than 0.3 dB/ft (1 dB/m), then the examination should be performed in accordance with specific instructions from the equipment manufacturer, and by personnel who have demonstrated their competence for these specific applications.

A-1925 SPECIAL APPLICATIONS OF GUIDED WAVE TESTING

For examination of road crossings and buried piping, the personnel carrying out the examination need to demonstrate their competence for these applications. In any circumstance in which there is significant signal attenuation, interpretation becomes much more complex. Special written procedures and practices will be provided for this type of inspection.

SUBSECTION B
DOCUMENTS ADOPTED BY SECTION V

See following pages.

ARTICLE 22
RADIOGRAPHIC STANDARDS

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STANDARD GUIDE FOR RADIOGRAPHIC EXAMINATION

SE-94

(Identical with ASTM Specification E94-04(2010).)

Standard Guide for Radiographic Examination

1. Scope

1.1 This guide covers satisfactory X-ray and gamma-ray radiographic examination as applied to industrial radiographic film recording. It includes statements about preferred practice without discussing the technical background which justifies the preference. A bibliography of several textbooks and standard documents of other societies is included for additional information on the subject.

1.2 This guide covers types of materials to be examined; radiographic examination techniques and production methods; radiographic film selection, processing, viewing, and storage; maintenance of inspection records; and a list of available reference radiograph documents.

NOTE 1—Further information is contained in Guide E999, Practice E1025, Test Methods E1030, and E1032.

1.3 *Interpretation and Acceptance Standards*—Interpretation and acceptance standards are not covered by this guide, beyond listing the available reference radiograph documents for castings and welds. Designation of accept - reject standards is recognized to be within the cognizance of product specifications and generally a matter of contractual agreement between producer and purchaser.

1.4 *Safety Practices*—Problems of personnel protection against X rays and gamma rays are not covered by this document. For information on this important aspect of radiography, reference should be made to the current document of the National Committee on Radiation Protection and Measurement, Federal Register, U.S. Energy Research and Development Administration, National Bureau of Standards, and to state and local regulations, if such exist. For specific radiation safety information refer to NIST Handbook ANSI 43.3, 21 CFR 1020.40, and 29 CFR 1910.1096 or state regulations for agreement states.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (See 1.4.)

1.6 If an NDT agency is used, the agency shall be qualified in accordance with Practice E543.

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E746 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E801 Practice for Controlling Quality of Radiological Examination of Electronic Devices

E999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1030 Test Method for Radiographic Examination of Metallic Castings

E1032 Test Method for Radiographic Examination of Weldments

E1079 Practice for Calibration of Transmission Densitometers

E1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E1316 Terminology for Nondestructive Examinations

E1390 Specification for Illuminators Used for Viewing Industrial Radiographs

E1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV

E1742 Practice for Radiographic Examination

E1815 Test Method for Classification of Film Systems for Industrial Radiography

2.2 *ANSI Standards:*

PH1.41 Specifications for Photographic Film for Archival Records, Silver-Gelatin Type, on Polyester Base

PH2.22 Methods for Determining Safety Times of Photographic Darkroom Illumination

PH4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers

T9.1 Imaging Media (Film)—Silver-Gelatin Type Specifications for Stability

T9.2 Imaging Media—Photographic Process Film Plate and Paper Filing Enclosures and Storage Containers

2.3 *Federal Standards:*

Title 21, Code of Federal Regulations (CFR) 1020.40, Safety Requirements of Cabinet X-Ray Systems

Title 29, Code of Federal Regulations (CFR) 1910.96, Ionizing Radiation (X-Rays, RF, etc.)

2.4 *Other Document:*

NBS Handbook ANSI N43.3 General Radiation Safety Installations Using NonMedical X-Ray and Sealed Gamma Sources up to 10 MeV

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology E1316.

4. Significance and Use

4.1 Within the present state of the radiographic art, this guide is generally applicable to available materials, processes, and techniques where industrial radiographic films are used as the recording media.

4.2 *Limitations*—This guide does not take into consideration special benefits and limitations resulting from the use of nonfilm recording media or readouts such as paper, tapes, xeroradiography, fluoroscopy, and electronic image intensification devices. Although reference is made to documents that may be used in the identification and grading, where applicable, of representative discontinuities in common metal castings and welds, no attempt has been made to set standards of acceptance for any material or production process. Radiography will be consistent in sensitivity and resolution only if the effect of all details of techniques, such as geometry, film, filtration, viewing, etc., is obtained and maintained.

5. Quality of Radiographs

5.1 To obtain quality radiographs, it is necessary to consider as a minimum the following list of items. Detailed information on each item is further described in this guide.

5.1.1 Radiation source (X-ray or gamma),
5.1.2 Voltage selection (X-ray),
5.1.3 Source size (X-ray or gamma),
5.1.4 Ways and means to eliminate scattered radiation,
5.1.5 Film system class,
5.1.6 Source to film distance,
5.1.7 Image quality indicators (IQI's),
5.1.8 Screens and filters,
5.1.9 Geometry of part or component configuration,
5.1.10 Identification and location markers, and
5.1.11 Radiographic quality level.

6. Radiographic Quality Level

6.1 Information on the design and manufacture of image quality indicators (IQI's) can be found in Practices E747, E801, E1025, and E1742.

6.2 The quality level usually required for radiography is 2 % (2-2T when using hole type IQI) unless a higher or lower quality is agreed upon between the purchaser and the supplier. At the 2 % subject contrast level, three quality levels of inspection, 2-1T, 2-2T, and 2-4T, are available through the design and application of the IQI (Practice E1025, Table 1). Other levels of inspection are available in Practice E1025 Table 1. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1T, 1-1T, and 1-2T by first determining that these quality levels can be maintained in production radiography.

NOTE 2—The first number of the quality level designation refers to IQI thickness expressed as a percentage of specimen thickness; the second number refers to the diameter of the IQI hole that must be visible on the radiograph, expressed as a multiple of penetrameter thickness, *T*.

6.3 If IQI's of material radiographically similar to that being examined are not available, IQI's of the required dimensions but of a lower-absorption material may be used.

6.4 The quality level required using wire IQI's shall be equivalent to the 2-2T level of Practice E1025 unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 of Practice E747 gives a list of various hole-type IQI's and the diameter of the wires of corresponding EPS with the applicable 1T, 2T, and 4T holes in the plaque IQI. Appendix X1 of Practice E747 gives the equation for calculating other equivalencies, if needed.

7. Energy Selection

7.1 X-ray energy affects image quality. In general, the lower the energy of the source utilized the higher the achievable radiographic contrast, however, other variables such as geometry and scatter conditions may override the potential advantage of higher contrast. For a particular energy, a range of thicknesses which are a multiple of the half value layer, may be radiographed to an acceptable quality level utilizing a particular X-ray machine or gamma ray source. In all cases the specified IQI (penetrameter) quality level must be shown on the radiograph. In general, satisfactory results can normally be obtained for X-ray energies between 100 kV to 500 kV in a range between 2.5 to 10 half value layers (HVL) of material thickness (see Table 1). This range may be extended by as much as a factor of 2 in some situations for X-ray energies in the 1 to 25 MV range primarily because of reduced scatter.

TABLE 1 Typical Steel HVL Thickness in Inches (mm) for Common Energies

Energy	Thickness, Inches (mm)
120 kV	0.10 (2.5)
150 kV	0.14 (3.6)
200 kV	0.20 (5.1)
250 kV	0.25 (6.4)
400 kV (Ir 192)	0.35 (8.9)
1 MV	0.57 (14.5)
2 MV (Co 60)	0.80 (20.3)
4 MV	1.00 (25.4)
6 MV	1.15 (29.2)
10 MV	1.25 (31.8)
16 MV and higher	1.30 (33.0)

8. Radiographic Equivalence Factors

8.1 The radiographic equivalence factor of a material is that factor by which the thickness of the material must be multiplied to give the thickness of a "standard" material (often steel) which has the same absorption. Radiographic equivalence factors of several of the more common metals are given in Table 2, with steel arbitrarily assigned a factor of 1.0. The factors may be used:

8.1.1 To determine the practical thickness limits for radiation sources for materials other than steel, and

8.1.2 To determine exposure factors for one metal from exposure techniques for other metals.

9. Film

9.1 Various industrial radiographic film are available to meet the needs of production radiographic work. However, definite rules on the selection of film are difficult to formulate because the choice depends on individual user requirements. Some user requirements are as follows: radiographic quality levels, exposure times, and various cost factors. Several methods are available for assessing image quality levels (see Test Method E746, and Practices E747 and E801). Information about specific products can be obtained from the manufacturers.

9.2 Various industrial radiographic films are manufactured to meet quality level and production needs. Test Method E1815 provides a method for film manufacturer classification of film systems. A film system consist of the film and associated film processing system. Users may obtain a classification table from the film manufacturer for the film system used in production radiography. A choice of film class can be made as provided in Test Method E1815. Additional specific details regarding classification of film systems is provided in Test Method E1815. ANSI Standards PH1.41, PH4.8, T9.1, and T9.2 provide specific details and requirements for film manufacturing.

10. Filters

10.1 *Definition*—Filters are uniform layers of material placed between the radiation source and the film.

10.2 *Purpose*—The purpose of filters is to absorb the softer components of the primary radiation, thus resulting in one or several of the following practical advantages:

10.2.1 Decreasing scattered radiation, thus increasing contrast.

10.2.2 Decreasing undercutting, thus increasing contrast.

10.2.3 Decreasing contrast of parts of varying thickness.

10.3 *Location*—Usually the filter will be placed in one of the following two locations:

10.3.1 As close as possible to the radiation source, which minimizes the size of the filter and also the contribution of the filter itself to scattered radiation to the film.

10.3.2 Between the specimen and the film in order to absorb preferentially the scattered radiation from the specimen. It should be noted that lead foil and other metallic screens (see 13.1) fulfill this function.

10.4 *Thickness and Filter Material*— The thickness and material of the filter will vary depending upon the following:

10.4.1 The material radiographed.

10.4.2 Thickness of the material radiographed.

10.4.3 Variation of thickness of the material radiographed.

10.4.4 Energy spectrum of the radiation used.

10.4.5 The improvement desired (increasing or decreasing contrast). Filter thickness and material can be calculated or determined empirically.

11. Masking

11.1 Masking or blocking (surrounding specimens or covering thin sections with an absorptive material) is helpful in reducing scattered radiation. Such a material can also be used

TABLE 2 Approximate Radiographic Equivalence Factors for Several Metals (Relative to Steel)

Metal	Energy Level									
	100 kV	150 kV	220 kV	250 kV	400 kV	1 MV	2 MV	4 to 25 MV	^{192}Ir	^{60}Co
Magnesium	0.05	0.05	0.08							
Aluminum	0.08	0.12	0.18						0.35	0.35
Aluminum alloy	0.10	0.14	0.18						0.35	0.35
Titanium		0.54	0.54		0.71	0.9	0.9	0.9	0.9	0.9
Iron/all steels	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.5	1.6	1.4	1.4	1.4	1.1	1.1	1.2	1.1	1.1
Zinc		1.4	1.3		1.3			1.2	1.1	1.0
Brass		1.4	1.3		1.3	1.2	1.1	1.0	1.1	1.0
Inconel X		1.4	1.3		1.3	1.3	1.3	1.3	1.3	1.3
Monel	1.7		1.2							
Zirconium	2.4	2.3	2.0	1.7	1.5	1.0	1.0	1.0	1.2	1.0
Lead	14.0	14.0	12.0			5.0	2.5	2.7	4.0	2.3
Hafnium			14.0	12.0	9.0	3.0				
Uranium			20.0	16.0	12.0	4.0		3.9	12.6	3.4

to equalize the absorption of different sections, but the loss of detail may be high in the thinner sections.

12. Back-Scatter Protection

12.1 Effects of back-scattered radiation can be reduced by confining the radiation beam to the smallest practical cross section and by placing lead behind the film. In some cases either or both the back lead screen and the lead contained in the back of the cassette or film holder will furnish adequate protection against back-scattered radiation. In other instances, this must be supplemented by additional lead shielding behind the cassette or film holder.

12.2 If there is any question about the adequacy of protection from back-scattered radiation, a characteristic symbol (frequently a ⅛-in. (3.2-mm) thick letter *B*) should be attached to the back of the cassette or film holder, and a radiograph made in the normal manner. If the image of this symbol appears on the radiograph as a lighter density than background, it is an indication that protection against back-scattered radiation is insufficient and that additional precautions must be taken.

13. Screens

13.1 *Metallic Foil Screens:*

13.1.1 Lead foil screens are commonly used in direct contact with the films, and, depending upon their thickness, and composition of the specimen material, will exhibit an intensifying action at as low as 90 kV. In addition, any screen used in front of the film acts as a filter (Section 10) to preferentially absorb scattered radiation arising from the specimen, thus improving radiographic quality. The selection of lead screen thickness, or for that matter, any metallic screen thickness, is subject to the same considerations as outlined in 10.4. Lead screens lessen the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure. To avoid image unsharpness due to screens, there should be intimate contact between the lead screen and the film during exposure.

13.1.2 Lead foil screens of appropriate thickness should be used whenever they improve radiographic quality or penetrameter sensitivity or both. The thickness of the front lead screens should be selected with care to avoid excessive filtration in the radiography of thin or light alloy materials, particularly at the lower kilovoltages. In general, there is no exposure advantage to the use of 0.005 in. in front and back lead screens below 125 kV in the radiography of ¼-in. (6.35-mm) or lesser thickness steel. As the kilovoltage is increased to penetrate thicker sections of steel, however, there is a significant exposure advantage. In addition to intensifying action, the back lead screens are used as protection against back-scattered radiation (see Section 12) and their thickness is only important for this function. As exposure energy is increased to penetrate greater thicknesses of a given subject material, it is customary to increase lead screen thickness. For radiography using radioactive sources, the minimum thickness of the front lead screen should be 0.005 in. (0.13 mm) for iridium-192, and 0.010 in. (0.25 mm) for cobalt-60.

13.2 *Other Metallic Screen Materials:*

13.2.1 Lead oxide screens perform in a similar manner to lead foil screens except that their equivalence in lead foil thickness approximates 0.0005 in. (0.013 mm).

13.2.2 Copper screens have somewhat less absorption and intensification than lead screens, but may provide somewhat better radiographic sensitivity with higher energy above 1 MV.

13.2.3 Gold, tantalum, or other heavy metal screens may be used in cases where lead cannot be used.

13.3 *Fluorescent Screens*—Fluorescent screens may be used as required providing the required image quality is achieved. Proper selection of the fluorescent screen is required to minimize image unsharpness. Technical information about specific fluorescent screen products can be obtained from the manufacturers. Good film-screen contact and screen cleanliness are required for successful use of fluorescent screens. Additional information on the use of fluorescent screens is provided in Appendix X1.

13.4 *Screen Care*—All screens should be handled carefully to avoid dents and scratches, dirt, or grease on active surfaces. Grease and lint may be removed from lead screens with a solvent. Fluorescent screens should be cleaned in accordance with the recommendations of the manufacturer. Screens showing evidence of physical damage should be discarded.

14. Radiographic Image Quality

14.1 *Radiographic image quality* is a qualitative term used to describe the capability of a radiograph to show flaws in the area under examination. There are three fundamental components of radiographic image quality as shown in Fig. 1. Each component is an important attribute when considering a specific radiographic technique or application and will be briefly discussed below.

14.2 *Radiographic contrast* between two areas of a radiograph is the difference between the film densities of those areas. The degree of radiographic contrast is dependent upon both subject contrast and film contrast as illustrated in Fig. 1.

14.2.1 *Subject contrast* is the ratio of X-ray or gamma-ray intensities transmitted by two selected portions of a specimen. Subject contrast is dependent upon the nature of the specimen (material type and thickness), the energy (spectral composition, hardness or wavelengths) of the radiation used and the intensity and distribution of scattered radiation. It is independent of time, milliamperage or source strength (curies), source distance and the characteristics of the film system.

14.2.2 *Film contrast* refers to the slope (steepness) of the film system characteristic curve. Film contrast is dependent upon the type of film, the processing it receives and the amount of film density. It also depends upon whether the film was exposed with lead screens (or without) or with fluorescent screens. Film contrast is independent, for most practical purposes, of the wavelength and distribution of the radiation reaching the film and, hence is independent of subject contrast. For further information, consult Test Method E1815.

14.3 *Film system granularity* is the objective measurement of the local density variations that produce the sensation of graininess on the radiographic film (for example, measured with a densitometer with a small aperture of $\leq$ 0.0039 in. (0.1

Radiographic Image Quality				
Radiographic Contrast		Film System Granularity	Radiographic Definition	
Subject Contrast	Film Contrast	• Grain size and distribution within the film emulsion • Processing conditions (type and activity of developer, temperature of developer, etc.) • Type of screens (that is, fluorescent, lead or none) • Radiation quality (that is, energy level, filtration, etc. • Exposure quanta (that is, intensity, dose, etc.)	Inherent Unsharpness	Geometric Unsharpness
Affected by: • Absorption differences in specimen (thickness, composition, density) • Radiation wavelength • Scattered radiation Reduced or enhanced by: • Masks and diaphragms • Filters • Lead screens • Potter-Bucky diaphragms	Affected by: • Type of film • Degree of development (type of developer, time, temperature and activity of developer, degree of agitation) • Film density • Type of screens (that is, fluorescent, lead or none)		Affected by: • Degree of screen-film contact • Total film thickness • Single or double emulsion coatings • Radiation quality • Type and thickness of screens (fluorescent, lead or none)	Affected by: • Focal spot or source physical size • Source-to-film distance • Specimen-to-film distance • Abruptness of thickness changes in specimen • Motion of specimen or radiation source

FIG. 1 Variables of Radiographic Image Quality

mm)). Graininess is the subjective perception of a mottled random pattern apparent to a viewer who sees small local density variations in an area of overall uniform density (that is, the visual impression of irregularity of silver deposit in a processed radiograph). The degree of granularity will not affect the overall spatial radiographic resolution (expressed in line pairs per mm, etc.) of the resultant image and is usually independent of exposure geometry arrangements. Granularity is affected by the applied screens, screen-film contact and film processing conditions. For further information on detailed perceptibility, consult Test Method E1815.

14.4 *Radiographic definition* refers to the sharpness of the image (both the image outline as well as image detail). Radiographic definition is dependent upon the inherent unsharpness of the film system and the geometry of the radiographic exposure arrangement (geometric unsharpness) as illustrated in Fig. 1.

14.4.1 *Inherent unsharpness (U_i)* is the degree of visible detail resulting from geometrical aspects within the film-screen system, that is, screen-film contact, screen thickness, total thickness of the film emulsions, whether single or double-coated emulsions, quality of radiation used (wavelengths, etc.) and the type of screen. Inherent unsharpness is independent of exposure geometry arrangements.

14.4.2 *Geometric unsharpness (U_g)* determines the degree of visible detail resultant from an "in-focus" exposure arrangement consisting of the source-to-film-distance, object-to-film-distance and focal spot size. Fig. 2(a) illustrates these conditions. Geometric unsharpness is given by the equation:

$$U_g = Ft/d_o \quad (1)$$

where:

U_g = geometric unsharpness,
F = maximum projected dimension of radiation source,
t = distance from source side of specimen to film, and
d_o = source-object distance.

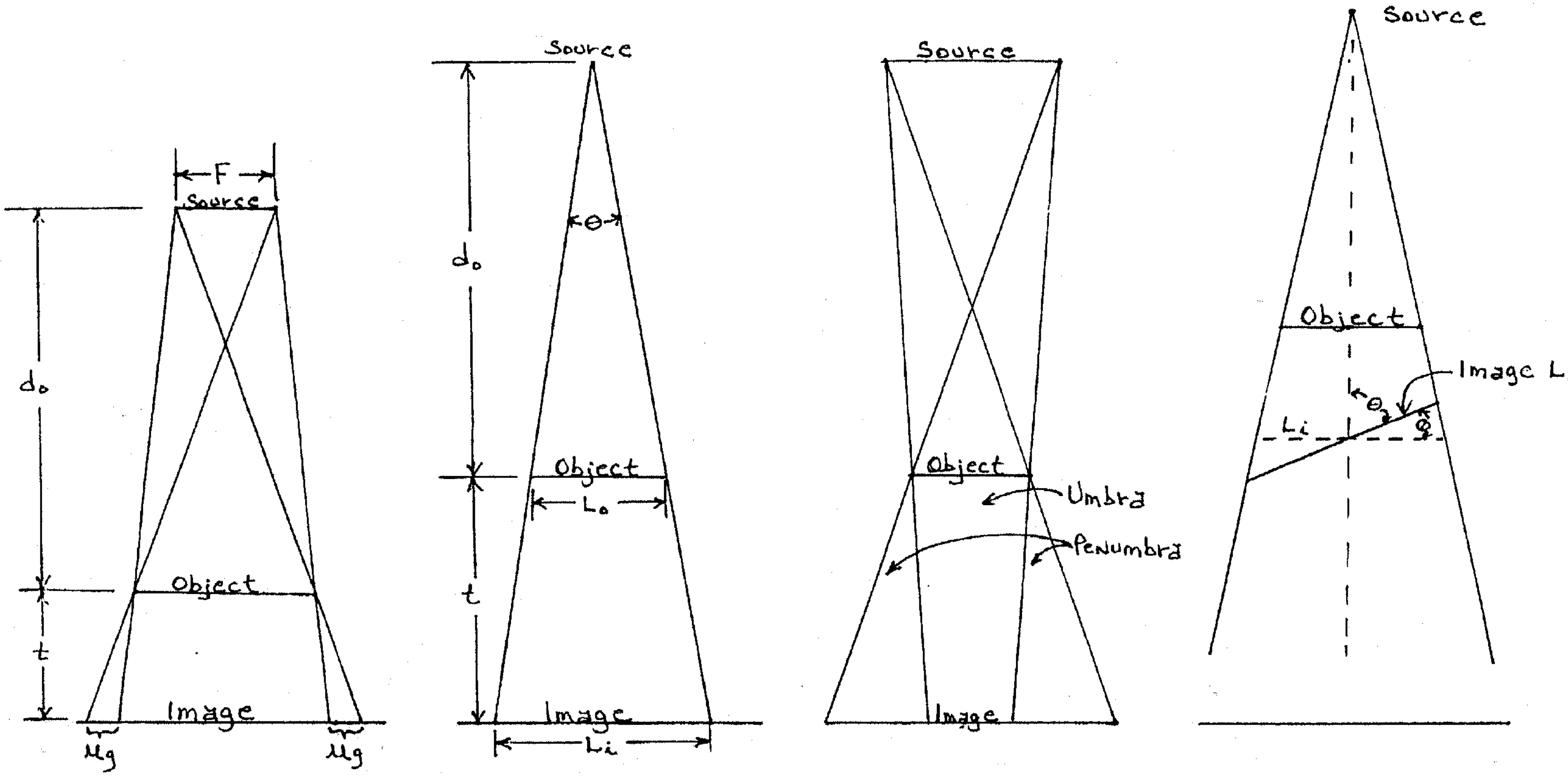
NOTE 3—d_o and t must be in the same units of measure; the units of U_g will be in the same units as F.

NOTE 4—A nomogram for the determination of U_g is given in Fig. 3 (inch-pound units). Fig. 4 represents a nomogram in metric units.
Example:
Given:
Source-object distance (d_o) = 40 in.,
Source size (F) = 500 mils, and
Source side of specimen to film distance (t) = 1.5 in.
Draw a straight line (dashed in Fig. 3) between 500 mils on the F scale and 1.5 in. on the t scale. Note the point on intersection (P) of this line with the pivot line. Draw a straight line (solid in Fig. 3) from 40 in. on the d_o scale through point P and extend to the U_g scale. Intersection of this line with the U_g scale gives geometrical unsharpness in mils, which in the example is 19 mils.

Inasmuch as the source size, F, is usually fixed for a given radiation source, the value of U_g is essentially controlled by the simple d_o/t ratio.

Geometric unsharpness (U_g) can have a significant effect on the quality of the radiograph; therefore source-to-film-distance (SFD) selection is important. The geometric unsharpness (U_g) equation, Eq 1, is for information and guidance and provides a means for determining geometric unsharpness values. The

FIG. 2 Effects of Object-Film Geometry



(a)

<u>Geometric Unsharpness</u>

d_0 = source-to-object distance

t = object-to-film distance

F = greatest dimension of source or focal spot

$\mu_g = Ft/d_0$

(b)

<u>Radiographic Enlargement</u>

d_0 = source-to-object distance

t = object-to-film distance

L_0 = dimension of object

L_i = dimension of image

$L_i - L_o = \Delta L = 2t \times \tan ½ \Theta$

Percentage enlargement = $\Delta L / L_0 \times 100$

(c)

<u>Radiographic Reduction</u>

(Image will be smaller than object or feature)

(d)

<u>Radiographic Distortion</u>

L_i = dimension of undistorted image

L_d = dimension of distorted image

$L_d - L_i = \Delta L$

Percentage distortion = $(\Delta L/L_i) \times 100$

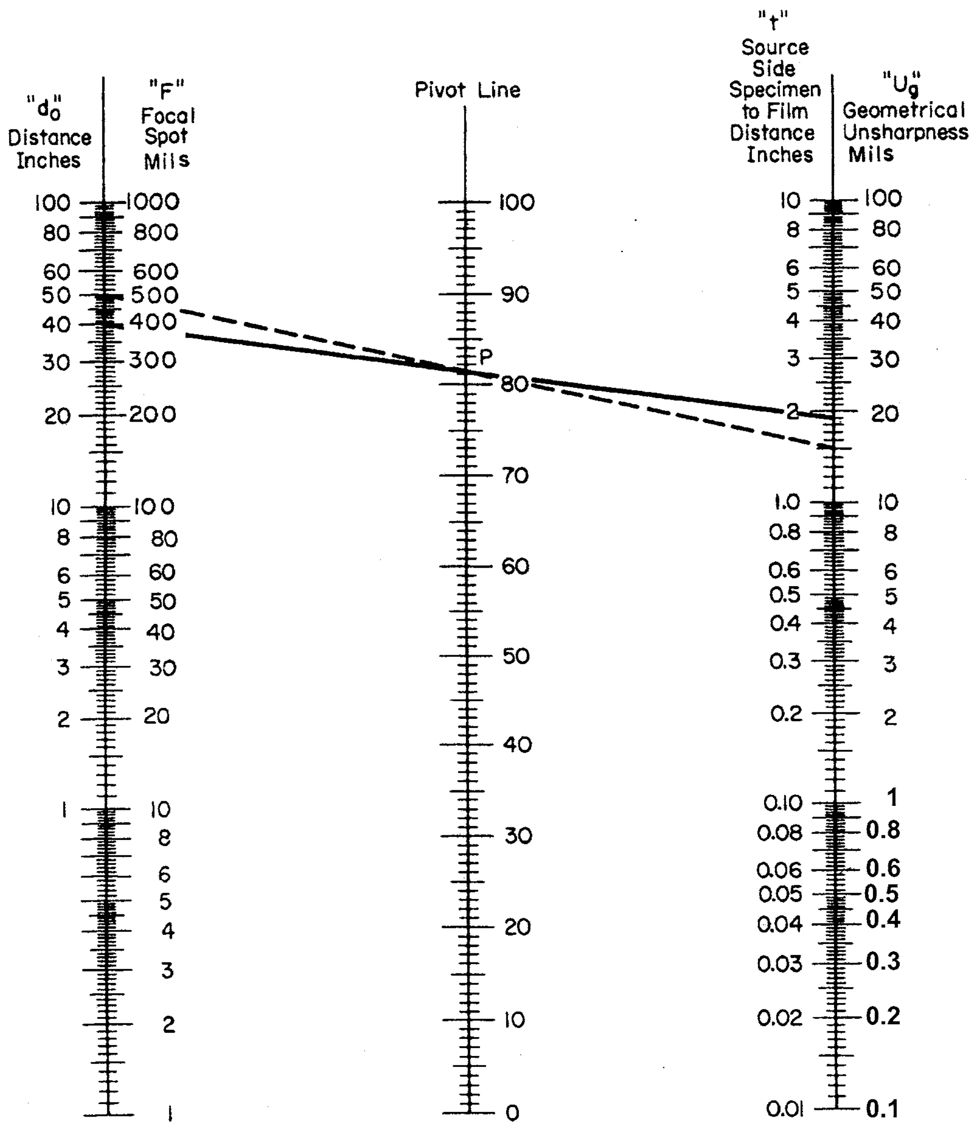


FIG. 3 Nomogram for Determining Geometrical Unsharpness (Inch-Pound Units)

amount or degree of unsharpness should be minimized when establishing the radiographic technique.

15. Radiographic Distortion

15.1 The radiographic image of an object or feature within an object may be larger or smaller than the object or feature itself, because the penumbra of the shadow is rarely visible in a radiograph. Therefore, the image will be larger if the object or feature is larger than the source of radiation, and smaller if object or feature is smaller than the source. The degree of reduction or enlargement will depend on the source-to-object and object-to-film distances, and on the relative sizes of the source and the object or feature (Fig. 2(*b*) and (*c*)).

15.2 The direction of the central beam of radiation should be perpendicular to the surface of the film whenever possible. The object image will be distorted if the film is not aligned perpendicular to the central beam. Different parts of the object image will be distorted different amount depending on the extent of the film to central beam offset (Fig. 2(*d*)).

16. Exposure Calculations or Charts

16.1 Development or procurement of an exposure chart or calculator is the responsibility of the individual laboratory.

16.2 The essential elements of an exposure chart or calculator must relate the following:

16.2.1 Source or machine,

16.2.2 Material type,

16.2.3 Material thickness,

16.2.4 Film type (relative speed),

16.2.5 Film density, (see Note 5),

16.2.6 Source or source to film distance,

16.2.7 Kilovoltage or isotope type,

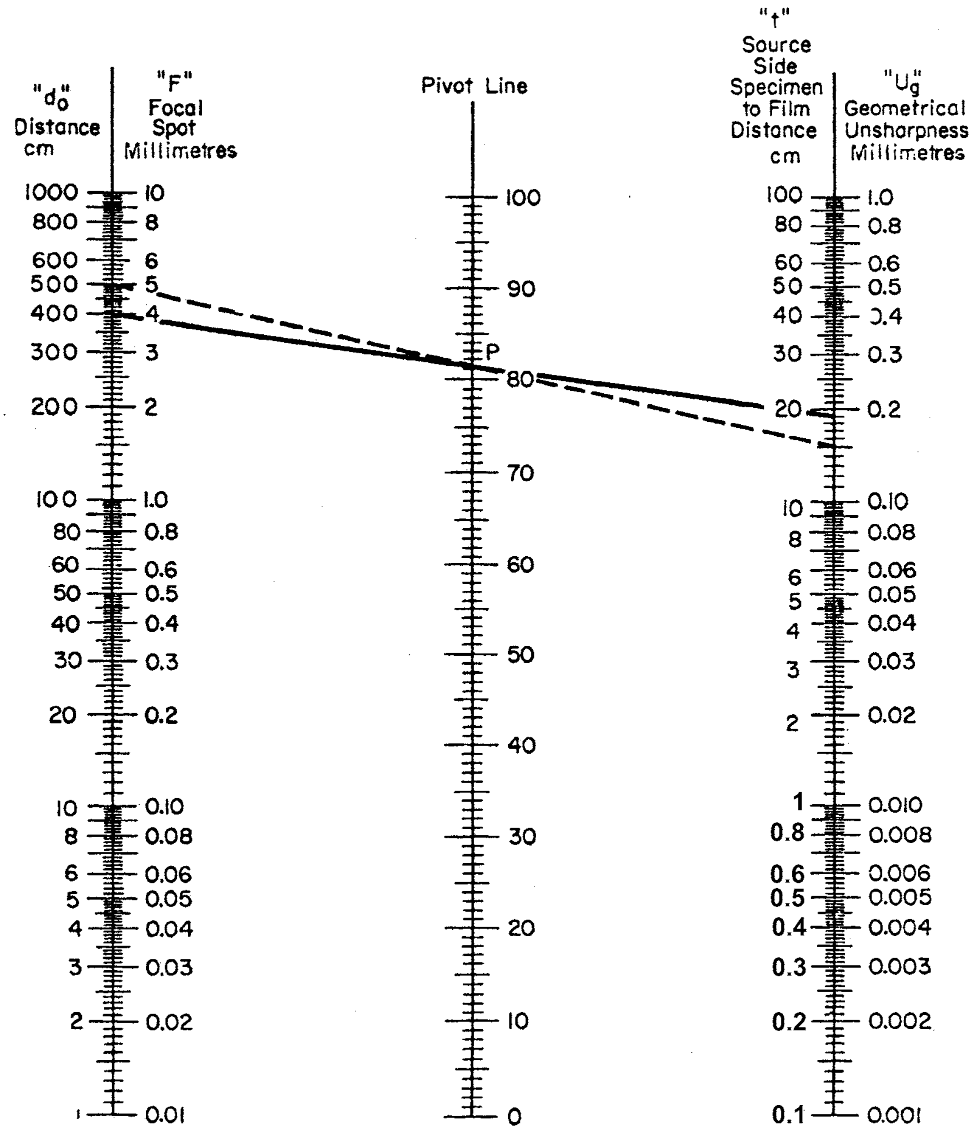


FIG. 4 Nomogram for Determining Geometrical Unsharpness (Metric Units)

NOTE 5—For detailed information on film density and density measurement calibration, see Practice E1079.

16.2.8 Screen type and thickness,

16.2.9 Curies or milliampere/minutes,

16.2.10 Time of exposure,

16.2.11 Filter (in the primary beam),

16.2.12 Time-temperature development for hand processing; access time for automatic processing; time-temperature development for dry processing, and

16.2.13 Processing chemistry brand name, if applicable.

16.3 The essential elements listed in 16.2 will be accurate for isotopes of the same type, but will vary with X-ray equipment of the same kilovoltage and milliampere rating.

16.4 Exposure charts should be developed for each X-ray machine and corrected each time a major component is replaced, such as the X-ray tube or high-voltage transformer.

16.5 The exposure chart should be corrected when the processing chemicals are changed to a different manufacturer's brand or the time-temperature relationship of the processor may be adjusted to suit the exposure chart. The exposure chart, when using a dry processing method, should be corrected based upon the time-temperature changes of the processor.

17. Technique File

17.1 It is recommended that a radiographic technique log or record containing the essential elements be maintained.

17.2 The radiographic technique log or record should contain the following:

17.2.1 Description, photo, or sketch of the test object illustrating marker layout, source placement, and film location.

17.2.2 Material type and thickness,

17.2.3 Source to film distance,

17.2.4 Film type,
17.2.5 Film density, (see Note 5),
17.2.6 Screen type and thickness,
17.2.7 Isotope or X-ray machine identification,
17.2.8 Curie or milliampere minutes,
17.2.9 IQI and shim thickness,
17.2.10 Special masking or filters,
17.2.11 Collimator or field limitation device,
17.2.12 Processing method, and
17.2.13 View or location.

17.3 The recommendations of 17.2 are not mandatory, but are essential in reducing the overall cost of radiography, and serve as a communication link between the radiographic interpreter and the radiographic operator.

18. Penetrameters (Image Quality Indicators)

18.1 Practices E747, E801, E1025, and E1742 should be consulted for detailed information on the design, manufacture and material grouping of IQI's. Practice E801 addresses IQI's for examination of electronic devices and provides additional details for positioning IQI's, number of IQI's required, and so forth.

18.2 Test Methods E746 and E1735 should be consulted for detailed information regarding IQI's which are used for determining relative image quality response of industrial film. The IQI's can also be used for measuring the image quality of the radiographic system or any component of the systems equivalent penetrameter sensitivity (EPS) performance.

18.2.1 An example for determining and EPS performance evaluation of several X-ray machines is as follows:

18.2.1.1 Keep the film and film processing parameters constant, and take multiple image quality exposures with all machines being evaluated. The machines should be set for a prescribed exposure as stated in the standard and the film density equalized. By comparison of the resultant films, the relative EPS variations between the machines can be determined.

18.2.2 Exposure condition variables may also be studied using this plaque.

18.2.3 While Test Method E746 plaque can be useful in quantifying relative radiographic image quality, these other applications of the plaque may be useful.

19. Identification of and Location Markers on Radiographs

19.1 *Identification of Radiographs:*

19.1.1 Each radiograph must be identified uniquely so that there is a permanent correlation between the part radiographed and the film. The type of identification and method by which identification is achieved shall be as agreed upon between the customer and inspector.

19.1.2 The minimum identification should at least include the following: the radiographic facility's identification and name, the date, part number and serial number, if used, for unmistakable identification of radiographs with the specimen. The letter *R* should be used to designate a radiograph of a repair area, and may include − 1, − 2, etc., for the number of repair.

19.2 *Location Markers:*

19.2.1 Location markers (that is, lead or high-atomic number metals or letters that are to appear as images on the radiographic film) should be placed on the part being examined, whenever practical, and not on the cassette. Their exact locations should also be marked on the surface of the part being radiographed, thus permitting the area of interest to be located accurately on the part, and they should remain on the part during radiographic inspection. Their exact location may be permanently marked in accordance with the customer's requirements.

19.2.2 Location markers are also used in assisting the radiographic interpreter in marking off defective areas of components, castings, or defects in weldments; also, sorting good and rejectable items when more than one item is radiographed on the same film.

19.2.3 Sufficient markers must be used to provide evidence on the radiograph that the required coverage of the object being examined has been obtained, and that overlap is evident, especially during radiography of weldments and castings.

19.2.4 Parts that must be identified permanently may have the serial numbers or section numbers, or both, stamped or written upon them with a marking pen with a special indelible ink, engraved, die stamped, or etched. In any case, the part should be marked in an area not to be removed in subsequent fabrication. If die stamps are used, caution is required to prevent breakage or future fatigue failure. The lowest stressed surface of the part should be used for this stamping. Where marking or stamping of the part is not permitted for some reason, a marked reference drawing or shooting sketch is recommended.

20. Storage of Film

20.1 Unexposed films should be stored in such a manner that they are protected from the effects of light, pressure, excessive heat, excessive humidity, damaging fumes or vapors, or penetrating radiation. Film manufacturers should be consulted for detailed recommendations on film storage. Storage of film should be on a "first in," "first out" basis.

20.2 More detailed information on film storage is provided in Guide E1254.

21. Safelight Test

21.1 Films should be handled under safelight conditions in accordance with the film manufacturer's recommendations. ANSI PH2.22 can be used to determine the adequacy of safelight conditions in a darkroom.

22. Cleanliness and Film Handling

22.1 Cleanliness is one of the most important requirements for good radiography. Cassettes and screens must be kept clean, not only because dirt retained may cause exposure or processing artifacts in the radiographs, but because such dirt may also be transferred to the loading bench, and subsequently to other film or screens.

22.2 The surface of the loading bench must be kept clean. Where manual processing is used cleanliness will be promoted by arranging the darkroom with processing facilities on one side and film-handling facilities on the other. The darkroom will then have a wet side and a dry side and the chance of chemical contamination of the loading bench will be relatively slight.

22.3 Films should be handled only at their edges, and with dry, clean hands to avoid finger marks on film surfaces.

22.4 Sharp bending, excessive pressure, and rough handling of any kind must be avoided.

23. Film Processing, General

23.1 To produce a satisfactory radiograph, the care used in making the exposure *must* be followed by equal care in processing. The most careful radiographic techniques can be nullified by incorrect or improper darkroom procedures.

23.2 Sections 24-26 provide general information for film processing. Detailed information on film processing is provided in Guide E999.

24. Automatic Processing

24.1 *Automatic Processing*—The essence of the automatic processing system is control. The processor maintains the chemical solutions at the proper temperature, agitates and replenishes the solutions automatically, and transports the films mechanically at a carefully controlled speed throughout the processing cycle. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film, processor, and chemical manufacturers be followed.

24.2 *Automatic Processing, Dry*—The essence of dry automatic processing is the precise control of development time and temperature which results in reproducibility of radiographic density. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film and processor manufacturers be followed.

25. Manual Processing

25.1 Film and chemical manufacturers should be consulted for detailed recommendations on manual film processing. This section outlines the steps for one acceptable method of manual processing.

25.2 *Preparation*—No more film should be processed than can be accommodated with a minimum separation of ½ in. (12.7 mm). Hangers are loaded and solutions stirred before starting development.

25.3 *Start of Development*—Start the timer and place the films into the developer tank. Separate to a minimum distance of ½ in. (12.7 mm) and agitate in two directions for about 15 s.

25.4 *Development*—Normal development is 5 to 8 min at 68°F (20°C). Longer development time generally yields faster film speed and slightly more contrast. The manufacturer's recommendation should be followed in choosing a development time. When the temperature is higher or lower, development time must be changed. Again, consult manufacturer-recommended development time versus temperature charts. Other recommendations of the manufacturer to be followed are replenishment rates, renewal of solutions, and other specific instructions.

25.5 *Agitation*—Shake the film horizontally and vertically, ideally for a few seconds each minute during development. This will help film develop evenly.

25.6 *Stop Bath or Rinse*—After development is complete, the activity of developer remaining in the emulsion should be neutralized by an acid stop bath or, if this is not possible, by rinsing with vigorous agitation in clear water. Follow the film manufacturer's recommendation of stop bath composition (or length of alternative rinse), time immersed, and life of bath.

25.7 *Fixing*—The films must not touch one another in the fixer. Agitate the hangers vertically for about 10 s and again at the end of the first minute, to ensure uniform and rapid fixation. Keep them in the fixer until fixation is complete (that is, at least twice the clearing time), but not more than 15 min in relatively fresh fixer. Frequent agitation will shorten the time of fixation.

25.8 *Fixer Neutralizing*—The use of a hypo eliminator or fixer neutralizer between fixation and washing may be advantageous. These materials permit a reduction of both time and amount of water necessary for adequate washing. The recommendations of the manufacturers as to preparation, use, and useful life of the baths should be observed rigorously.

25.9 *Washing*—The washing efficiency is a function of wash water, its temperature, and flow, and the film being washed. Generally, washing is very slow below 60°F (16°C). When washing at temperatures above 85°F (30°C), care should be exercised not to leave films in the water too long. The films should be washed in batches without contamination from new film brought over from the fixer. If pressed for capacity, as more films are put in the wash, partially washed film should be moved in the direction of the inlet.

25.9.1 The cascade method of washing uses less water and gives better washing for the same length of time. Divide the wash tank into two sections (may be two tanks). Put the films from the fixer in the outlet section. After partial washing, move the batch of film to the inlet section. This completes the wash in fresh water.

25.9.2 For specific washing recommendations, consult the film manufacturer.

25.10 *Wetting Agent*—Dip the film for approximately 30 s in a wetting agent. This makes water drain evenly off film which facilitates quick, even drying.

25.11 *Residual Fixer Concentrations*— If the fixing chemicals are not removed adequately from the film, they will in time cause staining or fading of the developed image. Residual fixer concentrations permissible depend upon whether the films are to be kept for commercial purposes (3 to 10 years) or must be of archival quality. Archival quality processing is desirable for all radiographs whenever average relative humidity and temperature are likely to be excessive, as is the case in tropical and subtropical climates. The method of determining residual fixer concentrations may be ascertained by reference to ANSI PH4.8, PH1.28, and PH1.41.

25.12 *Drying*—Drying is a function of (*1*) film (base and emulsion); (*2*) processing (hardness of emulsion after washing, use of wetting agent); and (*3*) drying air (temperature, humidity, flow). Manual drying can vary from still air drying at ambient temperature to as high as 140°F (60°C) with air circulated by a fan. Film manufacturers should again be contacted for recommended drying conditions. Take precaution to tighten film on hangers, so that it cannot touch in the dryer. Too hot a drying temperature at low humidity can result in uneven drying and should be avoided.

26. Testing Developer

26.1 It is desirable to monitor the activity of the radiographic developing solution. This can be done by periodic development of film strips exposed under carefully controlled conditions, to a graded series of radiation intensities or time, or by using a commercially available strip carefully controlled for film speed and latent image fading.

27. Viewing Radiographs

27.1 Guide E1390 provides detailed information on requirements for illuminators. The following sections provide general information to be considered for use of illuminators.

27.2 *Transmission*—The illuminator must provide light of an intensity that will illuminate the average density areas of the radiographs without glare and it must diffuse the light evenly over the viewing area. Commercial fluorescent illuminators are satisfactory for radiographs of moderate density; however, high light intensity illuminators are available for densities up to 3.5 or 4.0. Masks should be available to exclude any extraneous light from the eyes of the viewer when viewing radiographs smaller than the viewing port or to cover low-density areas.

27.3 *Reflection*—Radiographs on a translucent or opaque backing may be viewed by reflected light. It is recommended that the radiograph be viewed under diffuse lighting conditions to prevent excess glare. Optical magnification can be used in certain instances to enhance the interpretation of the image.

28. Viewing Room

28.1 Subdued lighting, rather than total darkness, is preferable in the viewing room. The brightness of the surroundings should be about the same as the area of interest in the radiograph. Room illumination must be so arranged that there are no reflections from the surface of the film under examination.

29. Storage of Processed Radiographs

29.1 Guide E1254 provides detailed information on controls and maintenance for storage of radiographs and unexposed film. The following sections provide general information for storage of radiographs.

29.2 Envelopes having an edge seam, rather than a center seam, and joined with a nonhygroscopic adhesive, are preferred, since occasional staining and fading of the image is caused by certain adhesives used in the manufacture of envelopes (see ANSI PH1.53).

30. Records

30.1 It is recommended that an inspection log (a log may consist of a card file, punched card system, a book, or other record) constituting a record of each job performed, be maintained. This record should comprise, initially, a job number (which should appear also on the films), the identification of the parts, material or area radiographed, the date the films are exposed, and a complete record of the radiographic procedure, in sufficient detail so that any radiographic techniques may be duplicated readily. If calibration data, or other records such as card files or procedures, are used to determine the procedure, the log need refer only to the appropriate data or other record. Subsequently, the interpreter's findings and disposition (acceptance or rejection), if any, and his initials, should also be entered for each job.

31. Reports

31.1 When written reports of radiographic examinations are required, they should include the following, plus such other items as may be agreed upon:

31.1.1 Identification of parts, material, or area.

31.1.2 Radiographic job number.

31.1.3 Findings and disposition, if any. This information can be obtained directly from the log.

32. Identification of Completed Work

32.1 Whenever radiography is an inspective (rather than investigative) operation whereby material is accepted or rejected, all parts and material that have been accepted should be marked permanently, if possible, with a characteristic identifying symbol which will indicate to subsequent or final examiners the fact of radiographic acceptance.

32.2 Whenever possible, the completed radiographs should be kept on file for reference. The custody of radiographs and the length of time they are preserved should be agreed upon between the contracting parties.

33. Keywords

33.1 exposure calculations; film system; gamma-ray; image quality indicator (IQI); radiograph; radiographic examination; radiographic quality level; technique file; X-ray

APPENDIX

(Nonmandatory Information)

X1. USE OF FLUORESCENT SCREENS

X1.1 *Description*—Fluorescent intensifying screens have a cardboard or plastic support coated with a uniform layer of inorganic phosphor (crystalline substance). The support and phosphor are held together by a radiotransparent binding material. Fluorescent screens derive their name from the fact that their phosphor crystals "fluoresce" (emit visible light) when struck by X or gamma radiation. Some phosphors like calcium tungstate ($CaWO_4$) give off blue light while others known as rare earth emit light green.

X1.2 *Purpose and Film Types*—Fluorescent screen exposures are usually much shorter than those made without screens or with lead intensifying screens, because radiographic films generally are more responsive to visible light than to direct X-radiation, gamma radiation, and electrons.

X1.2.1 Films fall into one of two categories: non-screen type film having moderate light response, and screen type film specifically sensitized to have a very high blue or green light response. Fluorescent screens can reduce conventional exposures by as much as 150 times, depending on film type.

X1.3 *Image Quality and Use*—The image quality associated with fluorescent screen exposures is a function of sharpness, mottle, and contrast. Screen sharpness depends on phosphor crystal size, thickness of the crystal layer, and the reflective base coating. Each crystal emits light relative to its size and in all directions thus producing a relative degree of image unsharpness. To minimize this unsharpness, screen to film contact should be as intimate as possible. Mottle adversely affects image quality in two ways. First, a "quantum" mottle is dependent upon the amount of X or gamma radiation actually absorbed by the fluorescent screen, that is, faster screen/film systems lead to greater mottle and poorer image quality. A" structural" mottle, which is a function of crystal size, crystal uniformity, and layer thickness, is minimized by using screens having small, evenly spaced crystals in a thin crystalline layer. Fluorescent screens are highly sensitive to longer wavelength scattered radiation. Consequently, to maximize contrast when this non-image forming radiation is excessive, fluorometallic intensifying screens or fluorescent screens backed by lead screens of appropriate thickness are recommended. Screen technology has seen significant advances in recent years, and today's fluorescent screens have smaller crystal size, more uniform crystal packing, and reduced phosphor thickness. This translates into greater screen/film speed with reduced unsharpness and mottle. These improvements can represent some meaningful benefits for industrial radiography, as indicated by the three examples as follows:

X1.3.1 *Reduced Exposure (Increased Productivity)*—There are instances when prohibitively long exposure times make conventional radiography impractical. An example is the inspection of thick, high atomic number materials with low curie isotopes. Depending on many variables, exposure time may be reduced by factors ranging from 2× to 105× when the appropriate fluorescent screen/film combination is used.

X1.3.2 *Improved Safety Conditions (Field Sites)*—Because fluorescent screens provide reduced exposure, the length of time that non-radiation workers must evacuate a radiographic inspection site can be reduced significantly.

X1.3.3 *Extended Equipment Capability* —Utilizing the speed advantage of fluorescent screens by translating it into reduced energy level. An example is that a 150 kV X-ray tube may do the job of a 300 kV tube, or that iridium 192 may be used in applications normally requiring cobalt 60. It is possible for overall image quality to be better at the lower kV with fluorescent screens than at a higher energy level using lead screens.

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STANDARD PRACTICE FOR DESIGN, MANUFACTURE AND MATERIAL GROUPING CLASSIFICATION OF WIRE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY

SE-747

(Identical with ASTM Specification E747-04(2010).)

Standard Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of wire image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 This practice covers the use of wire penetrameters as the controlling image quality indicator for the material thickness range from 6.4 to 152 mm (0.25 to 6.0 in.).

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B139/B139M Specification for Phosphor Bronze Rod, Bar, and Shapes

B150M Specification for Aluminum Bronze, Rod, Bar, and Shapes [Metric] (Withdrawn 2002)

B161 Specification for Nickel Seamless Pipe and Tube

B164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1316 Terminology for Nondestructive Examinations

2.2 *Other Standards:*

EN 462–1 Non-Destructive Testing—Image Quality of Radiographs-Part 1: Image Quality Indicators (Wire-Type)-Determination of Image Quality Value

3. Terminology

3.1 *Definitions*—The definitions of terms in Terminology E1316, Section D, relating to gamma and X-radiology, shall apply to the terms used in this practice.

4. Wire IQI Requirements

4.1 The quality of all levels of examination shall be determined by a set of wires conforming to the following requirements:

4.1.1 Wires shall be fabricated from materials or alloys identified or listed in accordance with 7.2. Other materials may be used in accordance with 7.3.

4.1.2 The IQI consists of sets of wires arranged in order of increasing diameter. The diameter sizes specified in Table 1 are established from a consecutive series of numbers taken in general from the ISO/R 10 series. The IQI shall be fabricated in accordance with the requirements specified in Figs. 1-8 and Tables 1-3. IQIs previously manufactured to the requirements of Annex A1 may be used as an alternate provided all other requirements of this practice are met.

4.1.3 Image quality indicator (IQI) designs other than those shown in Figs. 1-8 and Annex A1 are permitted by contractual agreement. If an IQI set as listed in Table 1 or Annex A1 is modified in size, it must contain the grade number, set identity, and essential wire. It must also contain two additional wires

TABLE 1 Wire IQI Sizes and Wire Identity Numbers

SET A		SET B	
Wire Diameter in. (mm)	Wire Identity	Wire Diameter in. (mm)	Wire Identity
0.0032 (0.08)[A]	1	0.010 (0.25)	6
0.004 (0.1)	2	0.013 (0.33)	7
0.005 (0.13)	3	0.016 (0.4)	8
0.0063 (0.16)	4	0.020 (0.51)	9
0.008 (0.2)	5	0.025 (0.64)	10
0.010 (0.25)	6	0.032 (0.81)	11
SET C		SET D	
Wire Diameter in. (mm)	Wire Identity	Wire Diameter in. (mm)	Wire Identity
0.032 (0.81)	11	0.10 (2.5)	16
0.040 (1.02)	12	0.126 (3.2)	17
0.050 (1.27)	13	0.160 (4.06)	18
0.063 (1.6)	14	0.20 (5.1)	19
0.080 (2.03)	15	0.25 (6.4)	20
0.100 (2.5)	16	0.32 (8)	21

[A] The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

TABLE 2 Wire Diameter Tolerances, mm

Wire Diameter (d), mm	Tolerance, mm
$0.000 < d \leq 0.125$	±0.0025
$0.125 < d \leq 0.25$	±0.005
$0.25 < d \leq 0.5$	±0.01
$0.50 < d \leq 1.6$	±0.02
$1.6 < d \leq 4$	±0.03
$4.0 < d \leq 8$	±0.05

TABLE 3 Wire Diameter Tolerances, in.

Wire Diameter (d), in.	Tolerance, in.
$0.000 < d \leq 0.005$	±0.0001
$0.005 < d \leq 0.010$	±0.0002
$0.010 < d \leq 0.020$	±0.0004
$0.020 < d \leq 0.063$	±0.0008
$0.063 < d \leq 0.160$	±0.0012
$0.160 < d \leq 0.320$	±0.0020

that are the next size larger and the next size smaller as specified in the applicable set listed in Table 1.

4.1.4 Each set must be identified using letters and numbers made of industrial grade lead or of a material of similar radiographic density. Identification shall be as shown on Figs. 1-8 or Annex A1, unless otherwise specified by contractual agreement.

4.1.5 European standard EN 462-1 contains similar provisions (with nominal differences-see Table A1.1) for wire image quality indicators as this standard (E747). International users of these type IQI standards who prefer the use of EN 462-1 for their particular applications should specify such alternate provisions within separate contractual arrangements from this standard.

5. Image Quality Indicator (IQI) Procurement

5.1 When selecting IQI's for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQI's that represent the required IQI thickness(s) and alloy(s).

6. Image Quality Levels

6.1 The quality level required using wire penetrameters shall be equivalent to the 2-2T level of Practice E1025 for hole-type IQI's unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 provides a list of various hole-type IQI's and the diameter of wires of corresponding equivalent penetrameter sensitivity (EPS) with the applicable 1T, 2T, and 4T holes in the IQI. This table can be used for determining 1T, 2T, and 4T quality levels. Appendix X1 gives the equation for calculating other equivalencies if needed.

6.2 In specifying quality levels, the contract, purchase order, product specification, or drawing should clearly indicate the thickness of material to which the quality level applies. Careful consideration of required quality levels is particularly important.

7. Material Groups

7.1 *General:*

7.1.1 Materials have been designated in eight groups based on their radiographic absorption characteristics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

7.1.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti) are identified 03, 02, and 01 respectively, for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper-base, nickel-base, and kindred alloys are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case and these IQI's are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 *Materials Groups:*

7.2.1 *Materials Group 01:*

7.2.1.1 Image quality indicators (IQI's) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.2.1.2 Use on all alloys of which titanium is the predominant alloying constituent.

7.2.2 *Materials Group 02:*

7.2.2.1 Image quality indicators (IQI's) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.2.2.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.2.3 *Materials Group 03:*

7.2.3.1 Image quality indicators (IQI's) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

TABLE 4 Wire Sizes Equivalent to Corresponding 1T, 2T, and 4T Holes in Various Hole Type Plaques

Plaque Thickness, in. (mm)	Plaque IQI Identification Number	Diameter of wire with EPS of hole in plaque, in. (mm)[A]		
		1T	2T	4T
0.005 (0.13)	5		0.0038 (0.09)	0.006 (0.15)
0.006 (0.16)	6		0.004 (0.10)	0.0067 (0.18)
0.008 (0.20)	8	0.0032 (0.08)	0.005 (0.13)	0.008 (0.20)
0.009 (0.23)	9	0.0035 (0.09)	0.0056 (0.14)	0.009 (0.23)
0.010 (0.25)	10	0.004 (0.10)	0.006 (0.15)	0.010 (0.25)
0.012 (0.30)	12	0.005 (0.13)	0.008 (0.20)	0.012 (0.28)
0.015 (0.38)	15	0.0065 (0.16)	0.010 (0.25)	0.016 (0.41)
0.017 (0.43)	17	0.0076 (0.19)	0.012 (0.28)	0.020 (0.51)
0.020 (0.51)	20	0.010 (0.25)	0.015 (0.38)	0.025 (0.63)
0.025 (0.64)	25	0.013 (0.33)	0.020 (0.51)	0.032 (0.81)
0.030 (0.76)	30	0.016 (0.41)	0.025 (0.63)	0.040 (1.02)
0.035 (0.89)	35	0.020 (0.51)	0.032 (0.81)	0.050 (1.27)
0.040 (1.02)	40	0.025 (0.63)	0.040 (0.02)	0.063 (1.57)
0.050 (1.27)	50	0.032 (0.81)	0.050 (1.27)	0.080 (2.03)
0.060 (1.52)	60	0.040 (1.02)	0.063 (1.57)	0.100 (2.54)
0.070 (1.78)	70	0.050 (1.27)	0.080 (2.03)	0.126 (3.20)
0.080 (2.03)	80	0.063 (1.57)	0.100 (2.54)	0.160 (4.06)
0.100 (2.50)	100	0.080 (2.03)	0.126 (3.20)	0.200 (5.08)
0.120 (3.05)	120	0.100 (2.54)	0.160 (4.06)	0.250 (6.35)
0.140 (3.56)	140	0.126 (3.20)	0.200 (5.08)	0.320 (8.13)
0.160 (4.06)	160	0.160 (4.06)	0.250 (6.35)	
0.200 (5.08)	200	0.200 (5.08)	0.320 (8.13)	
0.240 (6.10)	240	0.250 (6.35)		
0.280 (7.11)	280	0.320 (8.13)		

[A]Minimum plaque hole sizes were used as defined within Practice E1025.

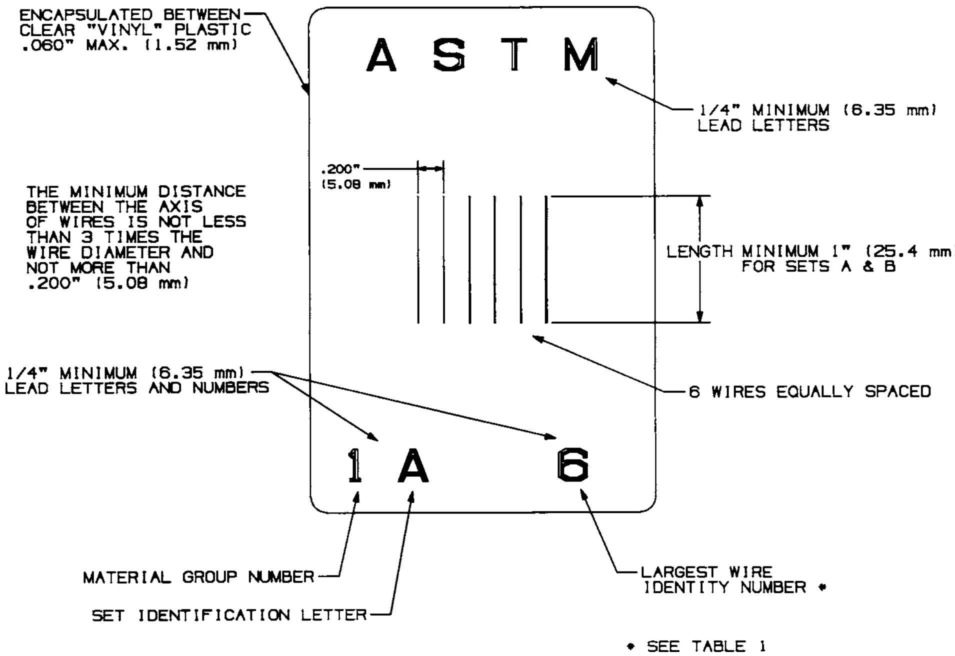


FIG. 1 Set A/Alternate 1

7.2.3.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.2.4 *Materials Group 1:*

7.2.4.1 Image quality indicators (IQI's) shall be made of carbon steel or Type 300 series stainless steel.

7.2.4.2 Use on all carbon steel, low-alloy steels, stainless steels, and manganese-nickel-aluminum bronze (Superston).

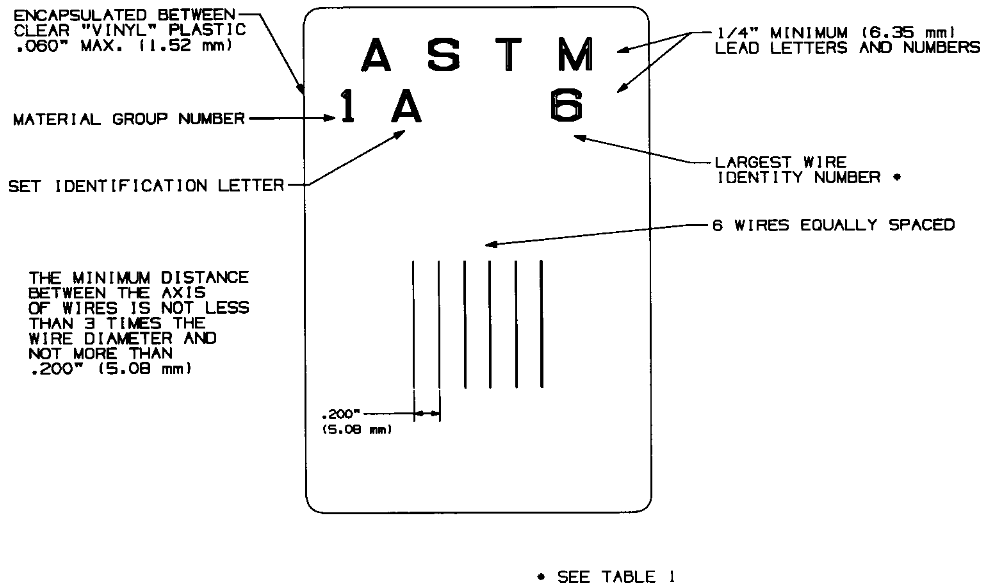


FIG. 2 Set A/Alternate 2

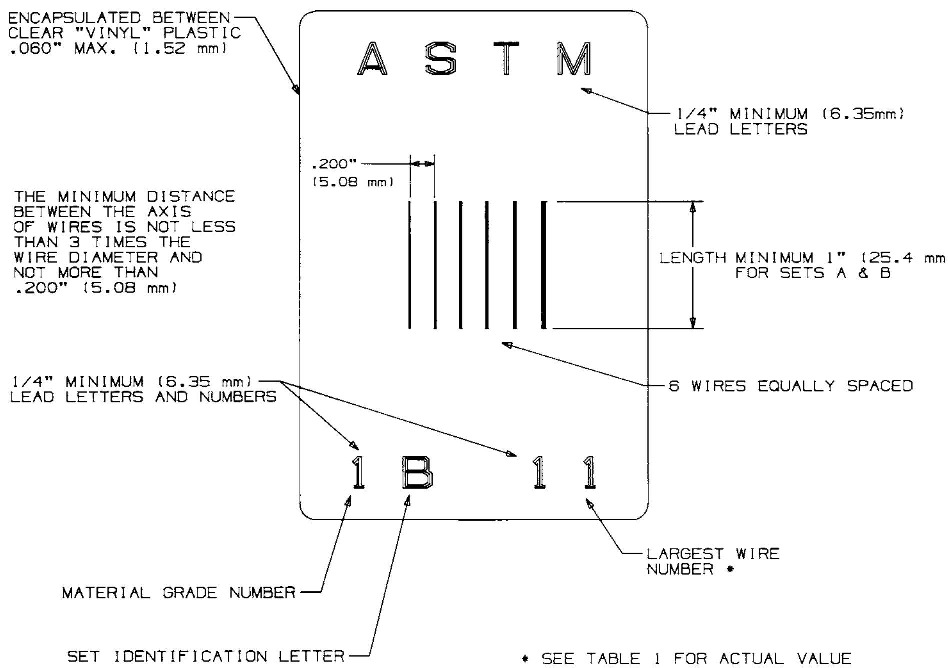


FIG. 3 Set B/Alternate 1

7.2.5 *Materials Group 2:*

7.2.5.1 Image quality indicators (IQI's) shall be made of aluminum bronze (Alloy No. 623 of Specification B150M) or equivalent, or nickel-aluminum bronze (Alloy No. 630 of Specification B150M) or equivalent.

7.2.5.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

7.2.6 *Materials Group 3:*

7.2.6.1 Image quality indicators (IQI's) shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). (See Specification B166).

7.2.6.2 Use on nickel-chromium-iron alloy and 18 % nickel-maraging steel.

7.2.7 *Materials Group 4:*

7.2.7.1 Image quality indicators (IQI's) shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B161) or equivalent.

7.2.7.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQI's may include the leaded brasses since

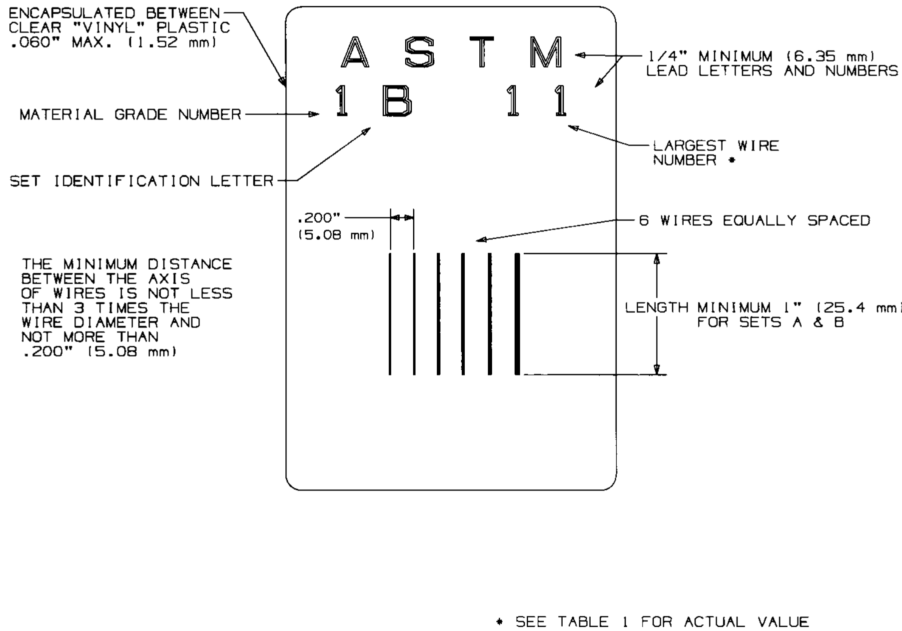


FIG. 4 Set B/Alternate 2

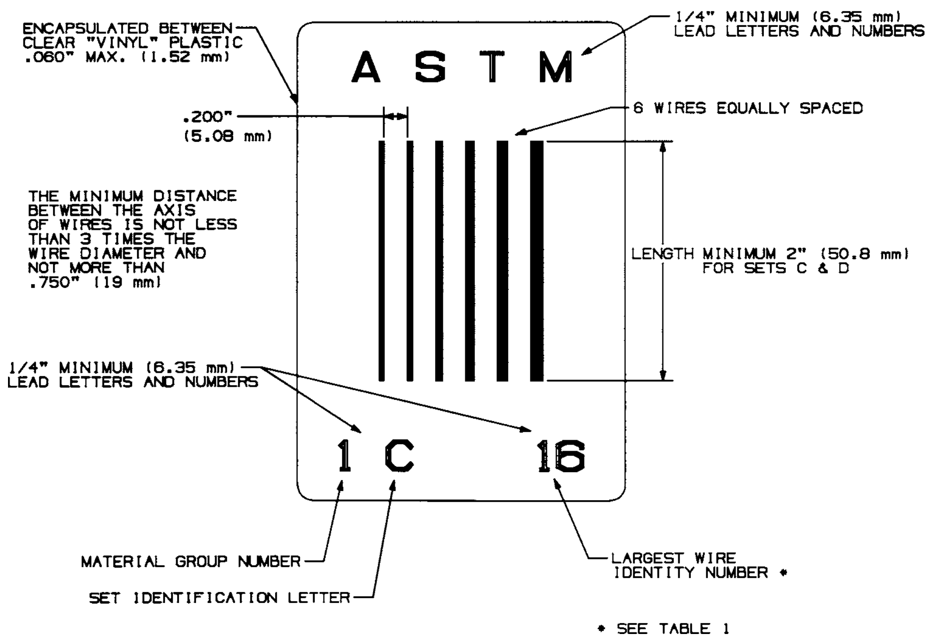


FIG. 5 Set C/Alternate 1

leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.2.8 *Materials Group 5:*

7.2.8.1 Image quality indicators (IQI's) shall be made of tin bronze (Alloy D of Specification B139/B139M).

7.2.8.2 Use on tin bronzes including gun-metal and valve bronze, or leaded-tin bronze of higher lead content than valve bronze. Group 5 IQI's may include bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 1—In developing the eight listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(*1*) *Group 2*—Haynes Alloy IN-100.

(*2*) *Group 3*—Haynes Alloy No. 713C, Hastelloy D, G.E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93,

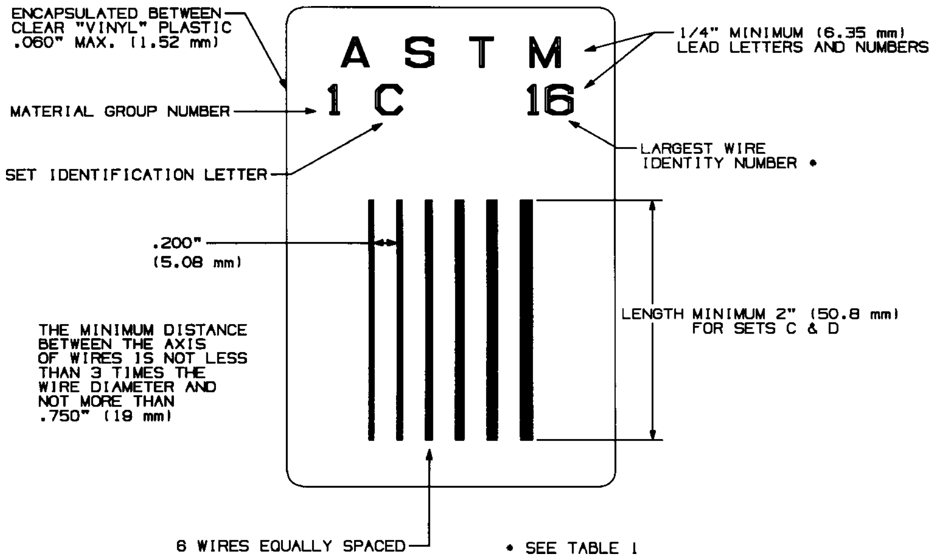


FIG. 6 Set C/Alternate 2

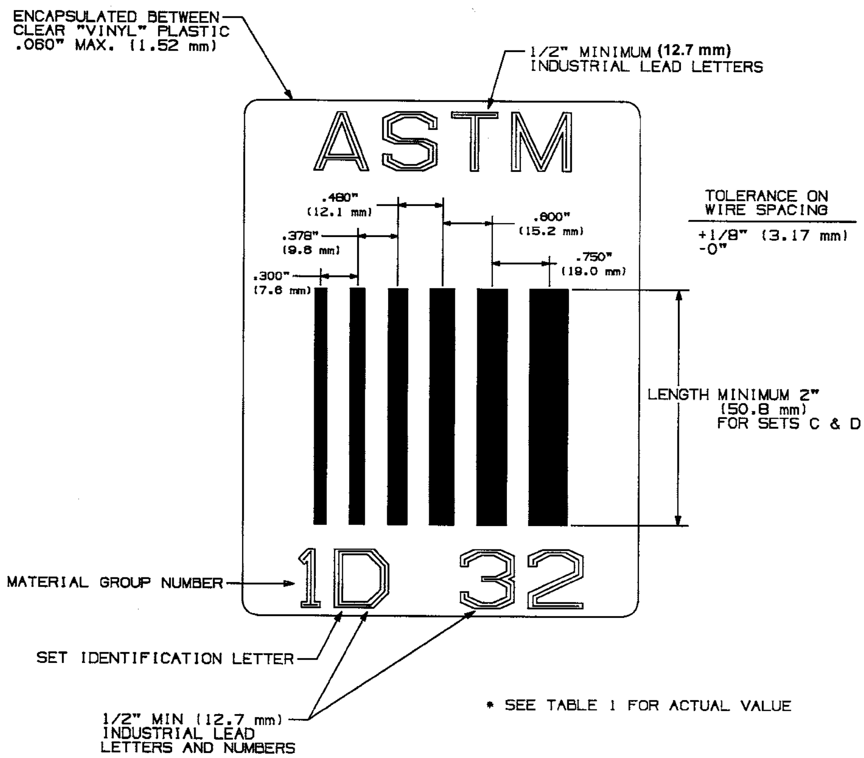


FIG. 7 Set D/Alternate 1

Inconel X, Inconel 718, and Haynes Stellite Alloy No. S-816.

(*3*) *Group 4*—Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(*4*) *Group 5*—Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. Image quality indicators (IQI's) of any of these materials are considered applicable for the materials that follow it.

NOTE 2—The committee formulating these recommendations recommend other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

7.3 *Method for Other Materials:*

7.3.1 For materials not herein covered, IQI's of the same materials, or any other material, may be used if the following

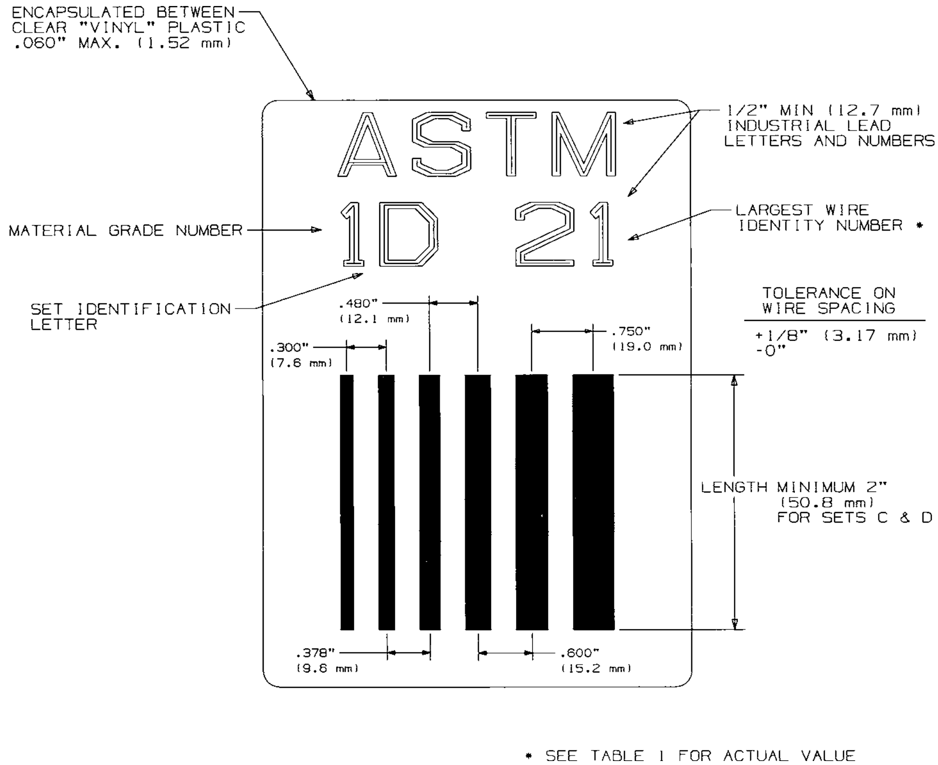


FIG. 8 Set D/Alternate 2

requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. Transmission densitometer measurements of the radiographic image of each material shall be made. The density of each image shall be between 2.0 and 4.0. If the image density of the IQI material is within 1.00 to 1.15 times (−0 % to + 15 %) the image density of the production material, IQI's made of that IQI material may be used in radiography of that production material. The percentage figure is based on the radiographic density of the IQI material.

7.3.2 It shall always be permissible to use IQI's of similar composition as the material being examined.

8. Image Quality Indicator (IQI) Certification

8.1 Documents shall be provided by the IQI manufacturer attesting to the following:

8.1.1 IQI identification alternate, if used.

8.1.2 Material type.

8.1.3 Conformance to specified tolerances for dimensional values.

8.1.4 ASTM standard designation, for example, ASTM E747—(year designation) used for manufacturing.

9. Precision and Bias

9.1 *Precision and Bias*—No statement is made about the precision or bias for indicating the quality of images since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

ANNEX

(Mandatory Information)

A1. ALTERNATE IQI IDENTIFICATION

A1.1 The use of IQI's with identifications as shown on Figs. A1.1-A1.9 and as listed in Table A1.1 is permitted as an acceptable alternate provided all other requirements of Practice E747 are satisfied.

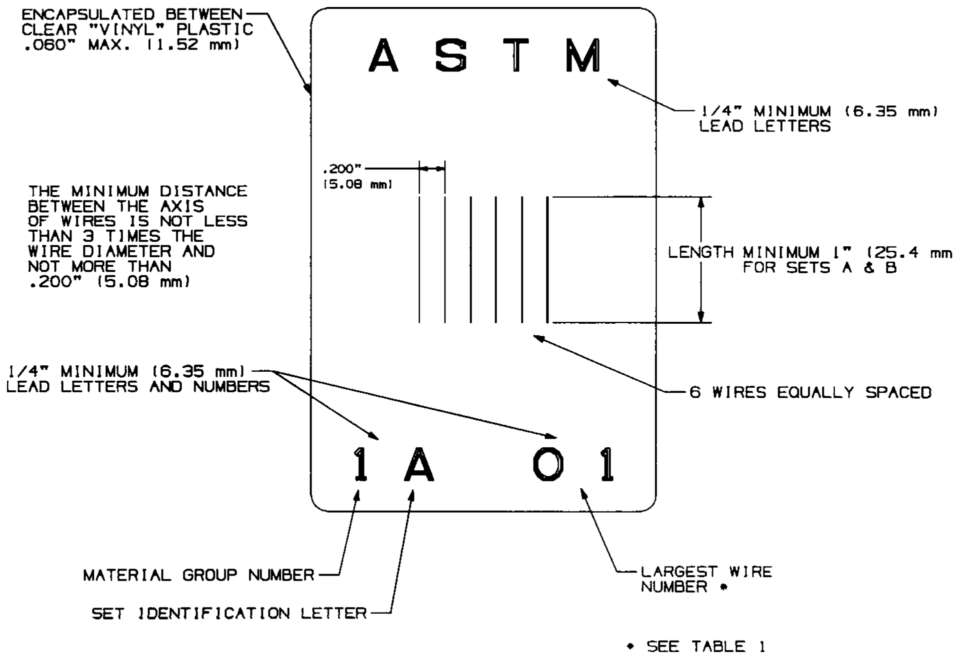


FIG. A1.1 Set A/Alternate 1

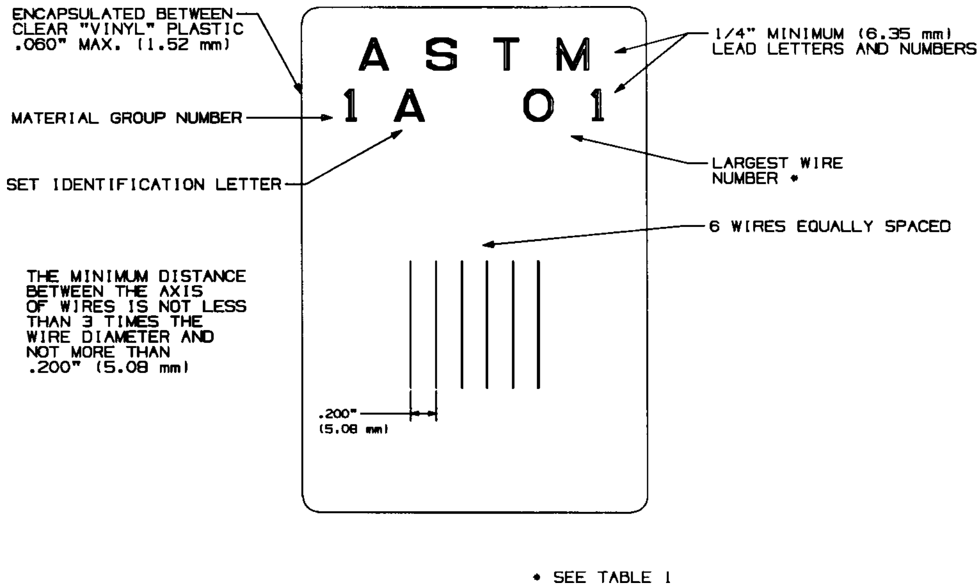


FIG. A1.2 Set A/Alternate 2

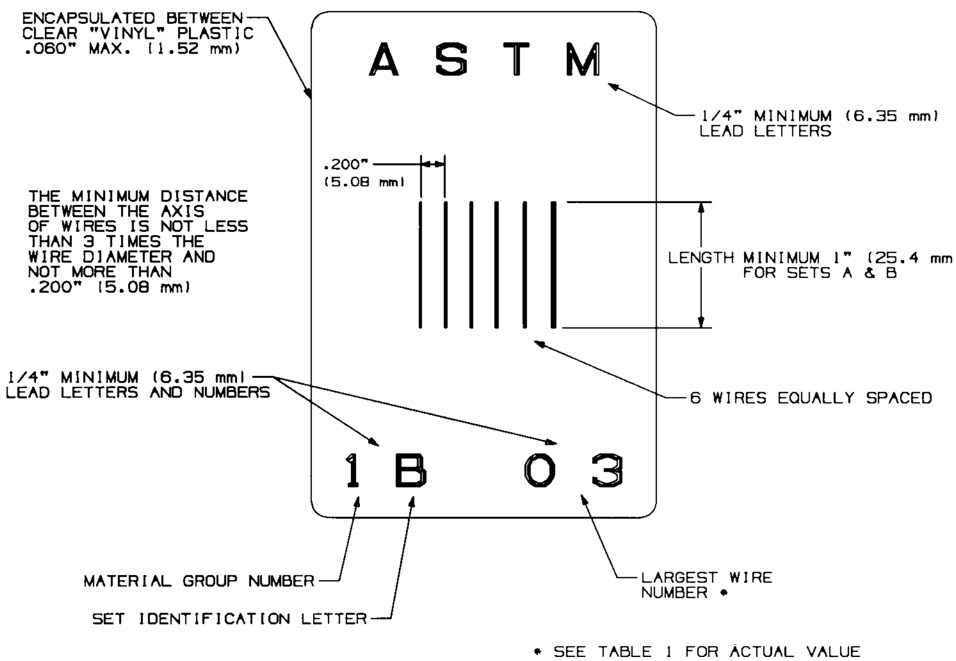


FIG. A1.3 Set B/Alternate 1

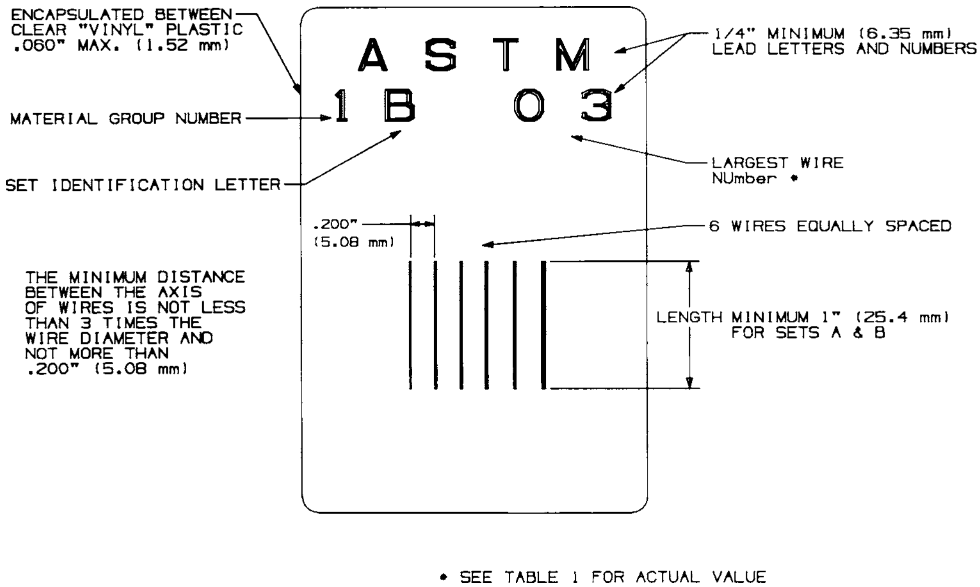


FIG. A1.4 Set B/Alternate 2

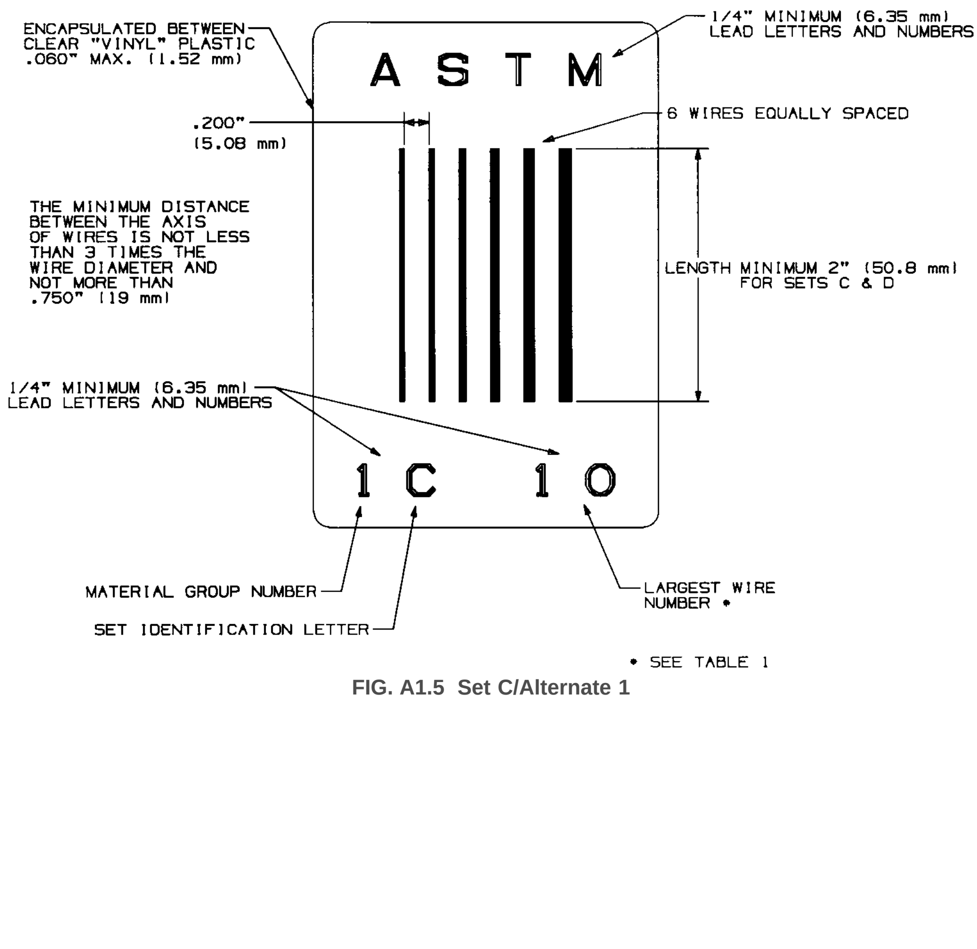


FIG. A1.5 Set C/Alternate 1

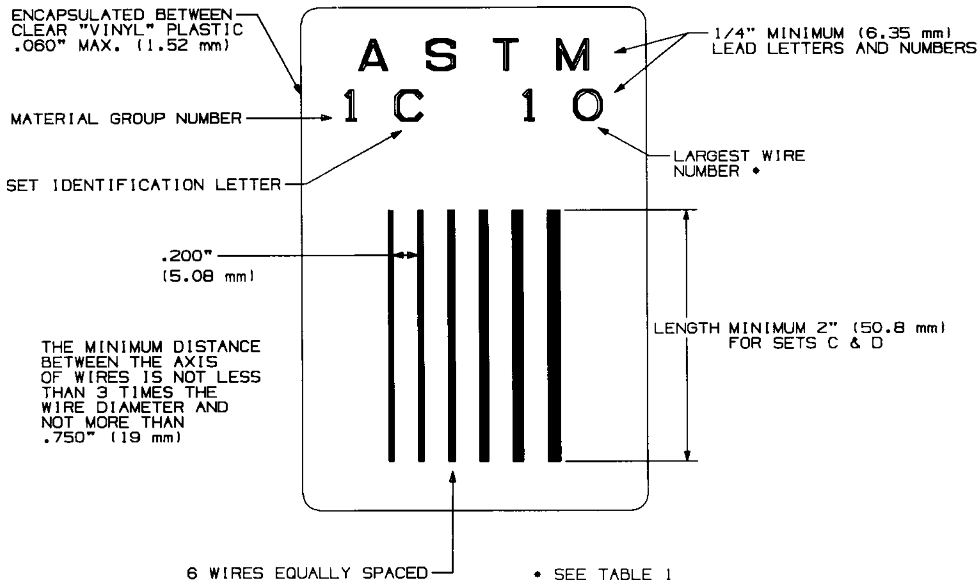


FIG. A1.6 Set C/Alternate 2

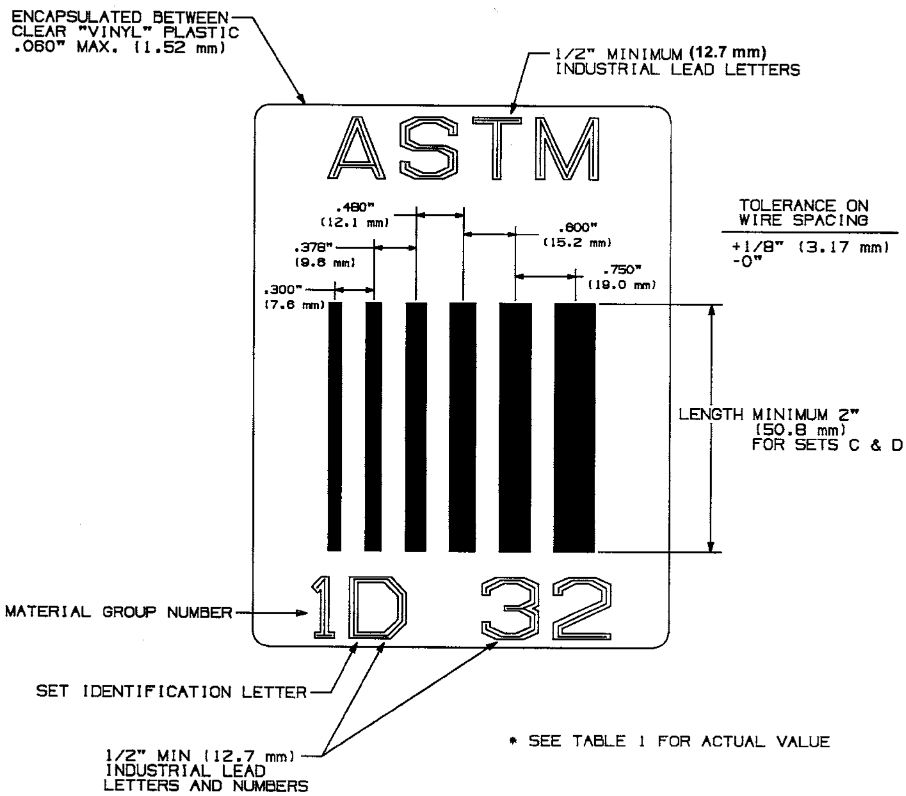


FIG. A1.7 Set D/Alternate 1

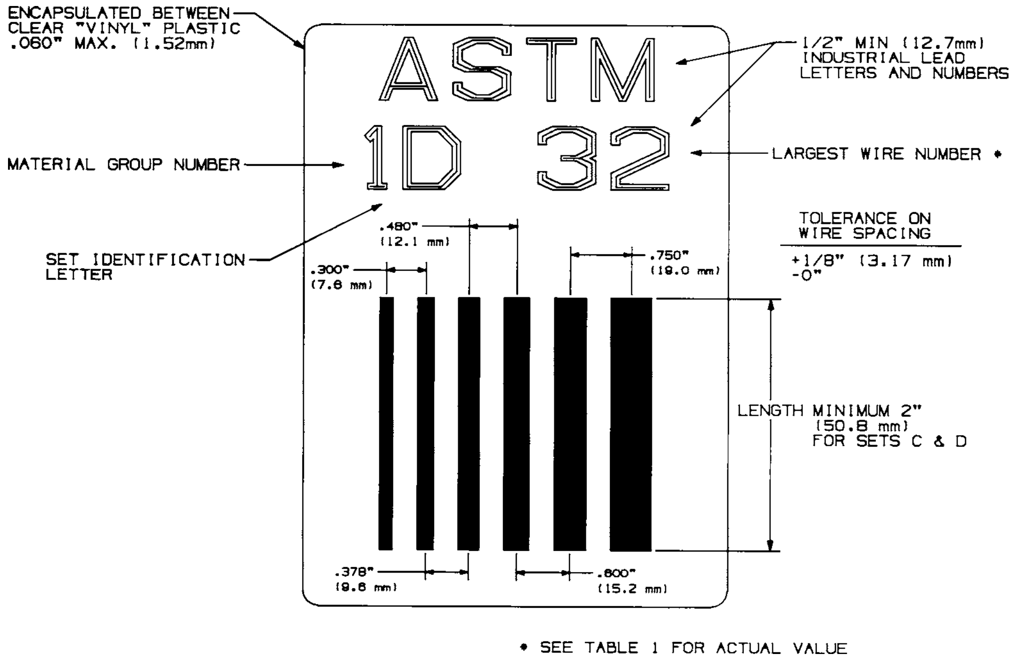
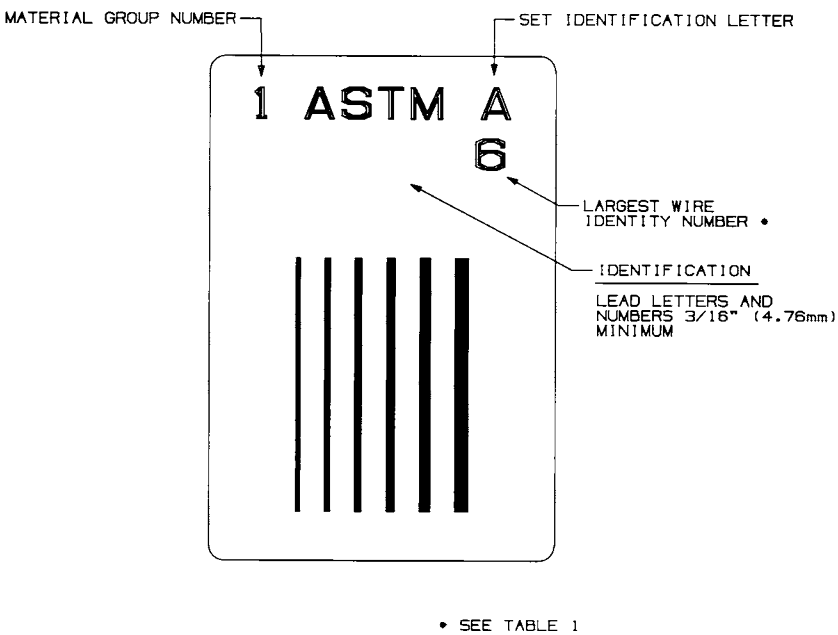


FIG. A1.8 Set D/Alternate 2



NOTE 1—All other IQI requirements as shown on Figs. 1-8 or Figs. A1.1-A1.8 apply.

FIG. A1.9 Alternate Identification Locations and Letter, Number Size-Typical All Sets (A, B, C, D)

TABLE A1.1 Penetrameter Sizes
Wire Diameter in. (mm)

SET A	ASTM Wire Identity	CEN Alternate Wire No. EN 462-1[A]	SET B	ASTM Wire Identity	CEN Alternate Wire No. EN 462-1[A]
0.0032(0.08)	1	W 17	0.010(0.25)	6	W 12
0.0040(0.1)	2	W 16	0.013(0.33)	7	W 11
0.0050(0.13)	3	W 15	0.016(0.41)	8	W 10
0.0063(0.16)	4	W 14	0.020(0.51)	9	W 9
0.0080(0.2)	5	W 13	0.025(0.64)	10	W 8
0.010(0.25)	6	W 12	0.032(0.81)	11	W 7
SET C	ASTM Wire Identity	CEN Alternate Wire No. EN 462-1[A]	SET D	ASTM Wire Identity	CEN Alternate Wire No. EN 462-1[A]
0.032(0.81)	11	W 7	0.100(2.5)	16	W 2
0.040(1.02)	12	W 6	0.126(3.2)	17	W 1
0.050(1.27)	13	W 5	0.160(4.06)	18	...
0.063(1.6)	14	W 4	0.20(5.1)	19	...
0.080(2.03)	15	W 3	0.25(6.4)	20	...
0.100(2.50)	16	W 2	0.32(8.1)	21	...

[A]As governed under provisions of paragraph 4.1.5 of this practice.

APPENDIX

(Nonmandatory Information)

X1. CALCULATING OTHER EQUIVALENTS

X1.1 The equation to determine the equivalencies between wire and (hole type) IQI's is as follows:

$$F^3 d^3 l = T^2 H^2 (\pi/4)$$

where:

F = form factor for wire, 0.79,
d = wire diameter, in. (mm),
l = effective length of wire, 0.3 in. (7.6 mm),
T = plaque thickness, in. (mm), and
H = diameter of hole, in. (mm).

X1.2 It should be noted that the wire and plaque (hole type) IQI sensitivities cannot be related by a fixed constant.

X1.3 Figs. X1.1 and X1.2 are conversion charts for hole type IQI's containing 1T and 2T holes to wires. The sensitivities are given as a percentage of the specimen thickness.

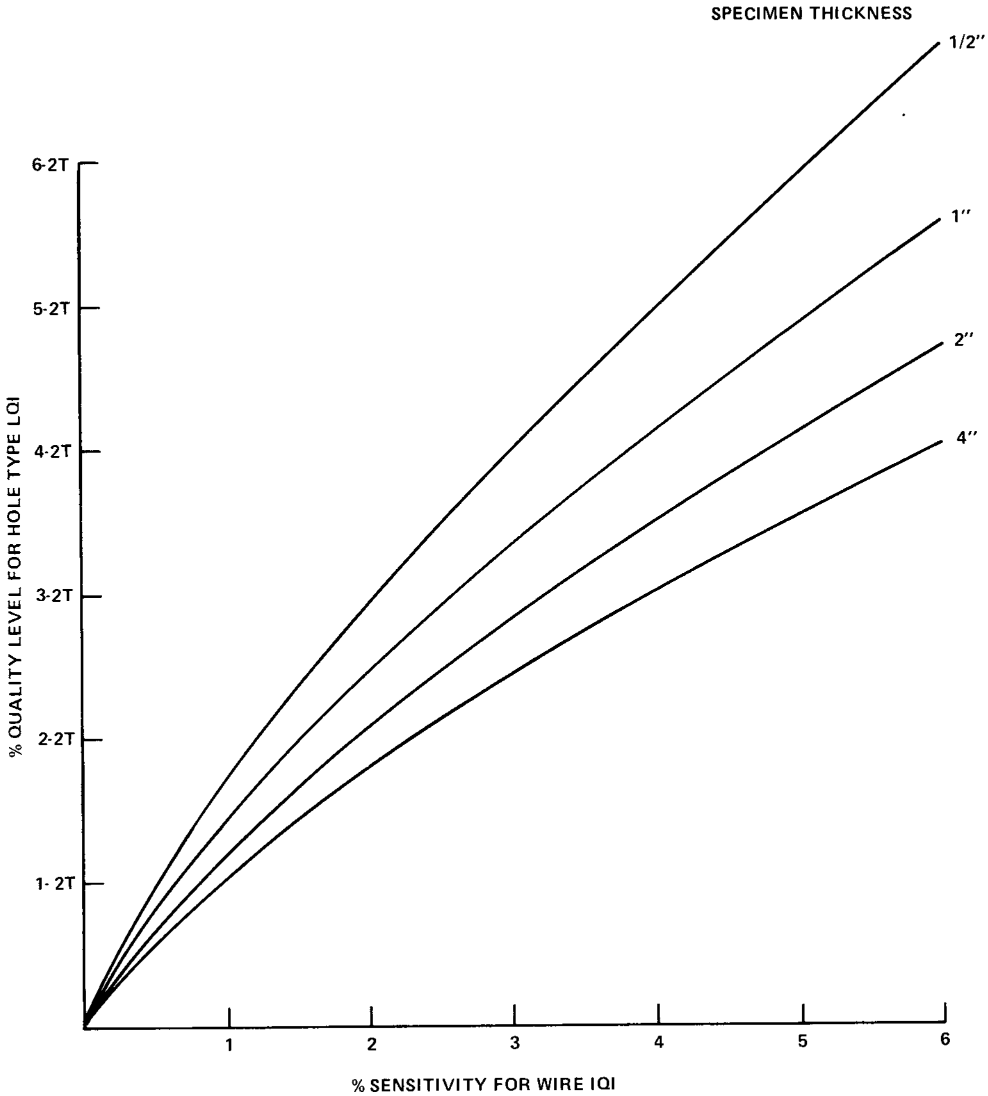


FIG. X1.1 Conversion Chart for 2-T Quality Level Holes to % Wire Sensitivity

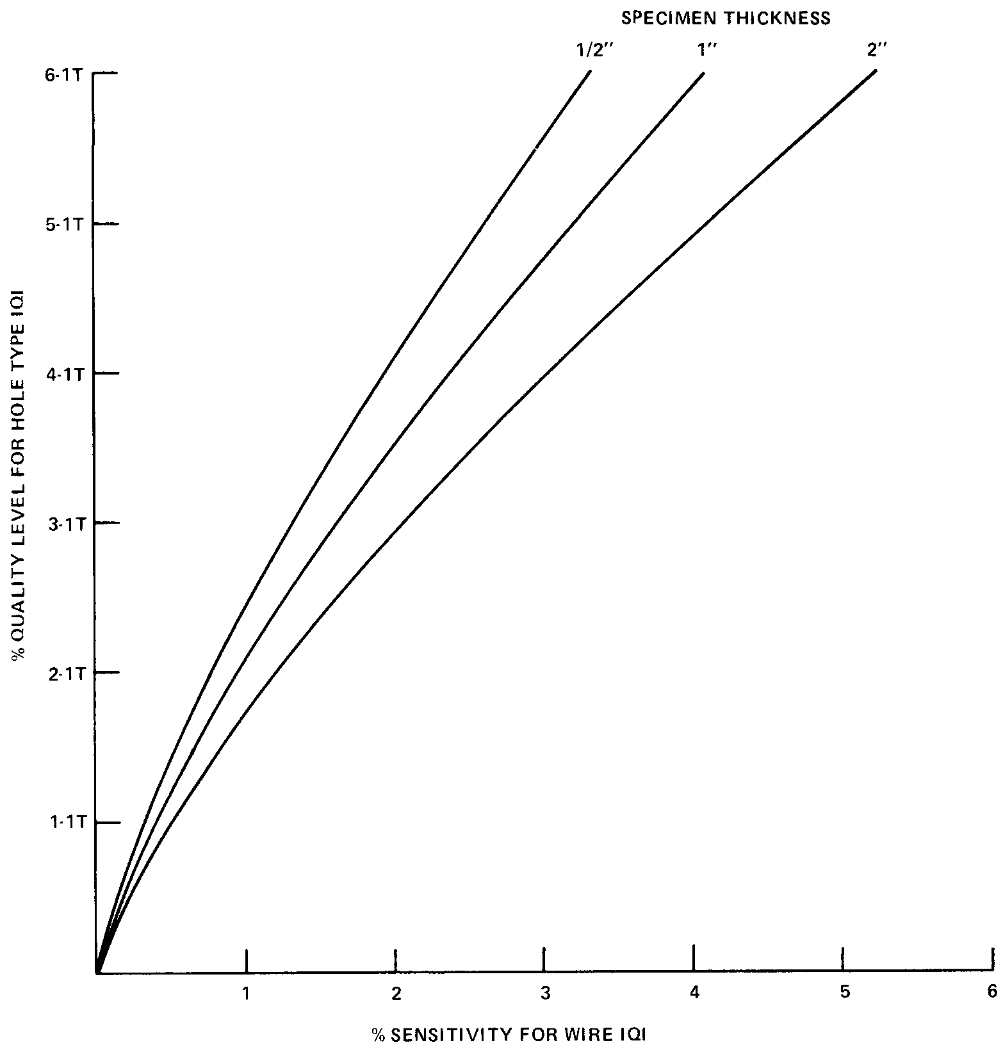


FIG. X1.2 Conversion Chart for 1-T Quality Level Holes to % Wire Sensitivity

STANDARD GUIDE FOR CONTROLLING THE QUALITY OF INDUSTRIAL RADIOGRAPHIC FILM PROCESSING

SE-999

(Identical with ASTM Specification E999-15.)

Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing

1. Scope

1.1 This guide establishes guidelines that may be used for the control and maintenance of industrial radiographic film processing equipment and materials. Effective use of these guidelines aid in controlling the consistency and quality of industrial radiographic film processing.

1.2 Use of this guide is limited to the processing of films for industrial radiography. This guide includes procedures for wet-chemical processes and dry processing techniques.

1.3 The necessity of applying specific control procedures such as those described in this guide is dependent, to a certain extent, on the degree to which a facility adheres to good processing practices as a matter of routine procedure.

1.4 If a nondestructive testing agency as described in Practice E543 is used to perform the examination, the testing agency shall meet the requirements of Practice E543.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of federal and local codes prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E94 Guide for Radiographic Examination

E543 Specification for Agencies Performing Nondestructive Testing

E1079 Practice for Calibration of Transmission Densitometers

E1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E1316 Terminology for Nondestructive Examinations

2.2 *ISO Standards:*

ISO 11699-2 Nondestructive testing—Industrial Radiographic Film—Part 2: Control of film processing by means of references values.

ISO 18917 Photography—Determination of residual thiosulfate and other related chemicals in processed photographic materials—Methods using iodine amylose, methylene blue, and silver sulfide

2.3 *ANSI Standards:*

IT 2.26 Photography—Photographic Materials– Determination of Safelight Conditions

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, see Terminology E1316.

4. Significance and Use

4.1 The provisions in this guide are intended to control the reliability or quality of the image development process only. The acceptability or quality of industrial radiographic films processed in this manner as well as the materials or products radiographed remain at the discretion of the user, or inspector, or both. It is further intended that this guide be used as an adjunct to and not a replacement for Guide E94.

5. Chemical Mixing for Manual and Automatic Processes

5.1 Any equipment that comes in contact with processing solutions should be made of glass, hard rubber, polyethylene, PVC, enameled steel, stainless steel, or other chemically inert materials. This includes materials such as plumbing, mixing impellers, and the cores of filter cartridges. Do not allow materials such as tin, copper, steel, brass, aluminum, or zinc to come into contact with processing solutions. These materials can cause solution contamination that may result in film fogging or rapid oxidation.

5.2 *Mixing Chemicals:*

5.2.1 Do not mix powdered chemicals in processor tanks, since undissolved particles may be left in the square corners of the tank. Mix solutions in separate containers made from materials specified in 5.1.

5.2.2 Carefully follow the manufacturer's package directions or formulas for mixing the chemicals. Start with the correct volume of water at the temperature specified in the instructions, and add chemicals in the order listed. During the mixing and use of radiographic film processing chemicals, be sure to observe all precautionary information on chemical containers and in instructions.

5.2.3 Proper mixing of chemicals can be verified with measurements of pH and specific gravity.

5.3 *Contamination of Solutions:*

5.3.1 Thoroughly clean all mixing equipment immediately after use to avoid contamination when the next solution is mixed. When mixing fixer from powder, make sure to add the powder carefully to the water in the mixing tank so fixer dust does not get into other processing solutions. When mixing any chemical, protect nearby tank solutions with floating lids and dust covers. The use of a vent hood is recommended as a safety precaution.

5.3.2 The water supply should either be de-ionized or filtered to 50 microns or better, so it is clean and sediment-free.

5.3.3 If large tanks are used for mixing, carefully mark the volume levels to be certain that volumes are correct.

5.3.4 Use separate mixers for developer solution and for fixer solution. If only one mixer is available, thoroughly rinse the mixer after each mix to avoid cross-contamination of chemicals. Use of impeller-type mixers provides rapid, thorough mixing. When positioning the impeller special caution should be taken in choosing angle and depth to minimize the amount of air being drawn into the solution. Over-mixing of the solutions can cause oxidation, especially with developers, and should be avoided. Rinse the shaft, impeller, and mounting clamp with water after use.

5.4 *Maintaining Equipment:*

5.4.1 Immediately clean all mixing equipment after use.

5.4.2 In addition to cleaning equipment immediately after use, wash any mixing apparatus that has been idle for a long period of time to eliminate dust and dirt that may have accumulated.

5.4.3 Processing hangers and tanks should be free of corrosion and chemical deposits. Encrusted deposits that accumulate in tanks, trays, and processing equipment which are difficult to remove by conventional cleaning, can be removed by using the specially formulated cleaning agents recommended by the chemical or equipment manufacturer.

6. Storage of Solutions

6.1 *In Original Containers*—Follow the manufacturer's storage and capacity recommendations packaged with the chemicals. Do not use chemicals that have been stored longer than recommended.

6.2 *In Replenisher or Process Tanks*—Wherever possible, protect solutions in tanks with floating lids and dust covers. In addition to preventing contaminants from entering solutions, floating lids and dust covers help to minimize oxidation and evaporation from the surface of the solutions. Evaporation can concentrate solutions and reduce temperatures causing precipitation of some of the solution constituents.

6.2.1 Store replenisher solutions for small volume operations in airtight containers. The caps of these containers should be free of corrosion and foreign particles that could prevent a tight fit.

6.3 *Temperature*—Store all solutions at normal room temperature, between 40 to 80°F (4 to 27°C). Storing solutions, particularly developer, at elevated temperatures can produce rapid oxidation resulting in loss of activity and a tendency to stain the film. Storage at too low a temperature, particularly of fixer solutions, can cause some solutions to crystallize, and the crystals may not redissolve even with heating and stirring.

6.4 *Deterioration*—Radiographic film processing chemicals can deteriorate either with age or with usage. Carefully follow the manufacturer's recommendations for storage life and useful capacity. Discard processing solutions when the recommended number of films has been processed or the recommended storage life of the prepared solution has been reached, whichever occurs first.

6.5 *Contamination:*

6.5.1 Liquid chemicals are provided in containers with tight-fitting tops. To avoid contamination, never interchange the top of one container with another. For this reason, it is common practice for radiographic film processing chemicals manufacturers to color code the container tops, that is, red for developer and blue for fixer.

6.5.2 Clearly label replenisher storage tanks with the solution that they contain and use that container only with that solution. If more than one developer or one fixer formulation are being used, a separate replenisher tank should be dedicated to each chemical. Differences in developer or fixer formulations from one manufacturer to another may contaminate similar solutions.

7. Processing

7.1 *Manual Processing:*

7.1.1 Follow the temperature recommendations from the film or solution manufacturer. Check thermometers and temperature-controlling devices periodically to be sure the process temperatures are correct. Process temperatures should be checked at least once per shift. Keep the temperature of the stop (if used), fixer, and wash water within ±5°F (±3°C) of the developer temperature. An unprotected mercury-filled thermometer should never be used for radiographic film processing applications because accidental breakage could result in serious mercury contamination.

7.1.2 Control of processing solution temperature and immersion time relationships are instrumental considerations when establishing a processing procedure that will consistently produce radiographs of desired density and quality. The actual time and temperature relationships established are governed largely by the industrial radiographic films and chemicals used and should be within the limits of the manufacturer's recommendations for those materials. When determining the immersion time for each solution ensure that the draining time is included. Draining time should be consistent from solution to solution. The darkroom timers used should be periodically checked for accuracy.

7.1.3 Agitate at specified intervals for the times recommended by the film or solution manufacturer.

7.1.4 As film is processed, the components of the processing solutions involved in the radiographic process are consumed. In addition, some solution adheres to the film and is carried over into the next solution while bromide ions and other by-products are released into the solutions. Replenishment is carried out to replace those components which have been consumed while, at the same time, reducing the level of by-products of the process. The volume of replenishment necessary is governed primarily by the number, size, and density of films processed. Manufacturer's recommendations for replenishment are based on these criteria and will generally provide suitable results for the expected life of the solution. In any case, maintain solution levels to ensure complete immersion of the film.

7.1.5 Newly mixed chemicals are often referred to as "fresh." "Seasoning" refers to the changes that take place in the processing solutions as films are processed after fresh chemicals have been added to the processor. As the processing solutions season, provided they are replenished appropriately, they will reach chemical equilibrium and the film speed and contrast will be consistent and stable. To bring freshly mixed solutions to a seasoned state very quickly, a chemical starter can be added or exposed films can be processed. When using developer starter solution follow the manufacturer's recommendations for the product. When using seasoning films expose the films with visible light and then develop three 14 by 17-in. (35 by 43-cm) films, or equivalent, per gallon (3.8 L) of developer, following the manufacturer's recommended processing cycle, replenishment, and wash rates.

NOTE 1—Seasoning films may be new films or films that may not be generally suitable for production purposes due to excessive gross fog (base plus fog) density, expiration of shelf life, or other reasons.

7.1.6 Handle all films carefully during the processing cycle and allow adequate time for the film to sufficiently drain before transferring it to the next solution. The use of a stop bath or clear water rinse between developing and fixing may also be appropriate. The stop bath or clear water rinse serve to arrest development and also aids in minimizing the amount of developer carried over into the fixer solution. Insufficient bath-to-bath drain time may cause excessive solution carryover which can contaminate and shorten the life of solutions in addition to causing undesirable effects on processed radiographs.

7.1.7 When washing films, a wetting agent may be appropriate to use to prevent water spots and streaking during drying. Prior to placing films in the dryer, ensure that the dryer is clean and that adequate heat and ventilation are provided. During drying, visually examine the films to determine the length of time required for sufficient drying.

7.2 *Automated Processing:*

7.2.1 Immersion time and solution temperature relationships can be more closely controlled with automatic processing since the equipment provides external gages for monitoring purposes. As a general guideline, follow the manufacturer's recommendations for industrial processing materials. However, the actual procedure used should be based on the variables encountered by the user and his particular needs. Check solutions daily or with established frequency based upon usage to ensure that temperatures are within the manufacturer's recommendations. Check the processor's thermometer with a secondary thermometer during normal maintenance procedures to verify correct processing temperatures within the manufacturer's specifications.

7.2.2 Transport speed should be checked during normal maintenance procedures by measuring the time it takes for a given length of film to pass a specific point. (For example, if the indicated machine speed is 2 ft/min, place two marks on a length of film 1 ft apart. The second mark should pass a specific location, such as the entrance to the processor, exactly 30 s after the first mark has passed the same point.) An optional method for measuring processor speed is to install a tachometer on the main drive motor and determine desired RPM/processing speed relationships.

7.2.3 Agitation is provided by the action of the processor rollers, recirculation pumps, and wash water flow. No external agitation is needed.

7.2.4 For processors with replenishment systems, use the replenishment rates recommended by the film or solution manufacturer.

7.2.4.1 Accurate replenishment increases the useful life of solutions to a great extent by replacing ingredients that are depleted and maintains the process at a constant, efficient level.

7.2.4.2 Replenishment rates should be verified during normal maintenance procedures to ensure that the correct volumes are being injected into the solutions. For installations processing very large amounts of film (in excess of two tank turnovers of solution per week), checks on replenishment rates should be made more frequently. Processor manufacturer's recommendations will generally provide an adequate procedure for checking replenishment volumes.

7.2.5 For seasoning freshly mixed developer solution, refer to the provisions in 7.1.5.

7.2.6 Always fill the fixer tank first, following the manufacturer's instructions, then rinse and fill the developer tank. This minimizes the possibility of fixer accidentally splashing into the developer solution. When replacing or removing processor racks, always use a splash guard to further reduce the possibility of contamination.

7.2.7 *Drying:*

7.2.7.1 Make sure the dryer is clean and that no foreign material has settled on the rollers. Routinely examine the ventilation system to ensure that air paths are not blocked and that films are uniformly dried. There are two types of dryer systems used in automatic film processors for industrial radiographic films:

(1) Convection dryers are circulating air systems with thermostatic controls. Normal drying temperatures range from 80 to 120°F when relative humidity (RH) conditions are approximately 40 to 75 %. Relative humidities above 75 % may require higher temperatures.

(2) Infrared (IR) dryers are based principally on absorption rather than temperature. Relative humidity has no adverse affect on infrared drying. Infrared energy levels are preset by the manufacturer and provide a range of dryer settings.

7.2.7.2 The dryer efficiency can be tested by processing six consecutive 14 by 17-in. (35 by 43-cm) production films, or equivalent and examining them immediately after the drying cycle is complete. If damp or undried areas are observed, increase the dryer setting. Should an increase in dryer temperature for convection dryers or an increase in energy for infrared dryers not dry the film, the following conditions should be investigated:

(1) Wash water that is too warm will cause excessive emulsion swelling. This can adversely affect film drying in convection dryers.

(2) Incoming dryer air that is either too humid or too cold can adversely affect film drying in the convection dryer.

(3) Check if oven-temperature devices or IR radiators, or both, are operational in infrared dryers.

(4) The fixer solution activity may not be in accordance to manufacturing recommendations and should be tested in accordance with 8.6.

8. Activity Testing of Solutions for Manual and Automatic Processing

8.1 *Certified Pre-exposed Control Strips*—The processing system can be controlled by use of certified pre-exposed control strips as specified by ISO 11699-2. Certified pre-exposed control strips are commercially available. Certified pre-exposed control strips are exposed to X-rays and are accompanied by a certificate from the film control strip manufacturer. Certified pre-exposed strips should be the same brand used in the facilities processing system. After processing, speed and contrast indexes are determined and compared to the reference speed and contrast values provided on the certificate.

8.2 Electronic sensitometers that expose film to white light are also commercially available. The user of electronic sensitometers should be aware that such usage, when accompanied by an appropriate white-light sensitive industrial film, results in greater response. Consequently, maintenance of developing parameters must be at a higher and more frequent level.

8.3 *Radiographic Monitoring Films*—To establish a reliable procedure for determining the activity of processing solutions, it will be necessary to provide a minimal amount of equipment and the proper selection and storage of radiographic control films. Radiographic films are made in batches where the characteristics may vary slightly between batches. These changes from emulsion to emulsion may be detectable and could be confused with the changes in the radiographic processing system.

8.3.1 *Sensitometric Step Tablets*—A metallic step wedge or other suitable object(s) of uniform material and varying thickness(es), of either aluminum or steel can be used with a given X-ray or gamma-ray exposure to create a sensitometric control strip. ISO 11699-2 describes the exposure of metallic step wedges for the production of sensitometric control films and the design of metallic step wedges.

8.3.2 Monitoring films must be properly stored to ensure that the film characteristics of the first sheet will be the same as the last sheet used. See Guide E1254

8.3.3 A monitoring film should be the same brand and type predominantly used in the facility's processing system

8.3.4 The first sensitometric film processed through freshly mixed and seasoned chemicals (see 7.1.5) will become the reference or standard for a box of control film.

8.3.5 Subsequent monitoring films are then produced on an as-needed basis and compared to the reference film to determine sensitometric changes within the processor. Generally, the higher the film volume processed, the more often QA checks should be performed.

8.3.6 If a monitoring film produces unusually high or low densities exceeding the tolerance limits, then the processing and sensitometric exposure conditions should be rechecked and repeated, if necessary. If the results are still out of tolerance, the cause must be located and corrected. Generally, a small adjustment in replenishment rates is necessary until a sensitometric film processor activity balance is established

8.3.7 Whenever it becomes necessary to change a monitoring film from one emulsion to another, two films each (from the new box and the old box) should be exposed and processed simultaneously to adjust for normal film manufacturing sensitometric variations.

8.4 *Densitometer:*

8.4.1 A transmission densitometer should be used capable of reading densities within the allowable range of optical densities utilized in production radiographs, with an aperture on the order of 1.0 to 3.0 mm in diameter. The densitometer should be calibrated in accordance with Practice E1079.

8.5 *Developer:*

8.5.1 The developer activity should be checked by processing a pre-exposed sensitometric strip, a radiograph of a step wedge, or a test part for measuring four film densities, one at base + fog (unexposed area of film) and three between 1.5 and 4.0 in three areas of interest (high, medium, and low densities). These four areas are also known as the Aim Film densities.

8.5.2 The film densities in the areas of interest being monitored should be within ±10 % of the original monitoring film density. Variations within this range are generally considered normal and should not adversely affect radiographic quality.

8.6 *Fixer:*

8.6.1 Fixer solution activity can be determined by measuring the clearing time. After the fixer solution has reached an operating temperature, place an unprocessed X-ray film into the fixer solution and measure the time required to remove the silver halide crystals; this is known as the clearing time. Removal of the X-ray film silver halide crystals can be observed when the X-ray film turns from a reflective color to a clear translucent film in the fixer. The film should remain in the fixer solution for twice the amount of time necessary for it to become clear. The film should be periodically agitated during manual processing.

8.6.2 If physical examination shows unfixed spots or areas, the fixer should be discarded. Unfixed areas may appear as dull, nonreflective areas that may be yellowish in color depending on the actual lack of fixer activity.

8.7 *Wash:*

8.7.1 Proper washing is necessary to remove residual fixer from the film. If not removed from the film, these chemicals will cause subsequent damage (staining) and deterioration of the radiographic image, especially in low-density areas.

8.7.2 The effectiveness of washing may be checked using the *residual thiosulfate chemicals* test described in Guide E94 or ISO 18917.

8.7.3 If physical examination of the films after washing shows dirt or scum that was not present before washing, the wash tanks should be drained and cleaned. Drain wash tanks whenever they are not being used. In order to minimize washing artifacts it is recommended that *"cleanup" films* be processed at start up to clear out scum and foreign material. *"Cleanup" films* are commercially available. The use of algaecides is also recommended to retard the growth of organisms within the wash bath.

8.7.4 The newer cold-water-type processors do not require a control valve to regulate water temperatures. However, many older-type processors require that the incoming water temperature be set within certain limits of the developer temperature. Exceeding these limits may not allow the processor to adequately control the developer temperature, which may cause density variations.

8.8 *Safelights:*

8.8.1 Follow all safelight recommendations for the particular film being used. Refer to the product or manufacturer's instructions for recommended safelight filter, bulb wattage, and minimum safelight distance.

8.8.2 The sensitivity of most film emulsions does not end abruptly at a particular wavelength – most emulsions are somewhat sensitive to wavelengths outside the intended range, including wavelengths transmitted by the recommended safelight filter. Therefore, always minimize the exposure of photographic materials to safelight illumination. Safelight conditions can be tested and verified as prescribed in ANSI IT 2.26.

9. Records

9.1 Accurate records should be kept of the following items:

9.1.1 Brand name and model of processor, if used.

9.1.2 Brand names and batch number of chemicals used.

9.1.3 Time of development.

9.1.4 Temperature of processing chemicals.

9.1.5 Date new chemicals were placed in use.

9.1.6 Replenishment rates.

10. Maintenance

10.1 Maintenance schedules provided by the manufacturer for preventive maintenance should be adhered to in order to assure consistent chemical and mechanical operation as set forth by the manufacturer.

11. Keywords

11.1 automatic processing; film; manual processing; processing; radiographic; solutions

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF HOLE-TYPE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY

SE-1025

(Identical with ASTM Specification E1025-11.)

Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of hole-type image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B139/B139M Specification for Phosphor Bronze Rod, Bar, and Shapes

B150/B150M Specification for Aluminum Bronze Rod, Bar, and Shapes

B164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire

E746 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV

E1316 Terminology for Nondestructive Examinations

E2662 Practice for Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications

2.2 *Department of Defense (DoD) Documents:*

MIL-I-24768 Insulation, Plastics, Laminated, Thermosetting; General Specification for

3. Terminology

3.1 *Definitions*—The definitions of terms relating to gamma and X-radiology in Terminology E1316, Section D, shall apply to the terms used in this practice.

4. Hole-Type IQI Requirements

4.1 Image quality indicators (IQIs) used to determine radiologic-image quality levels shall conform to the following requirements.

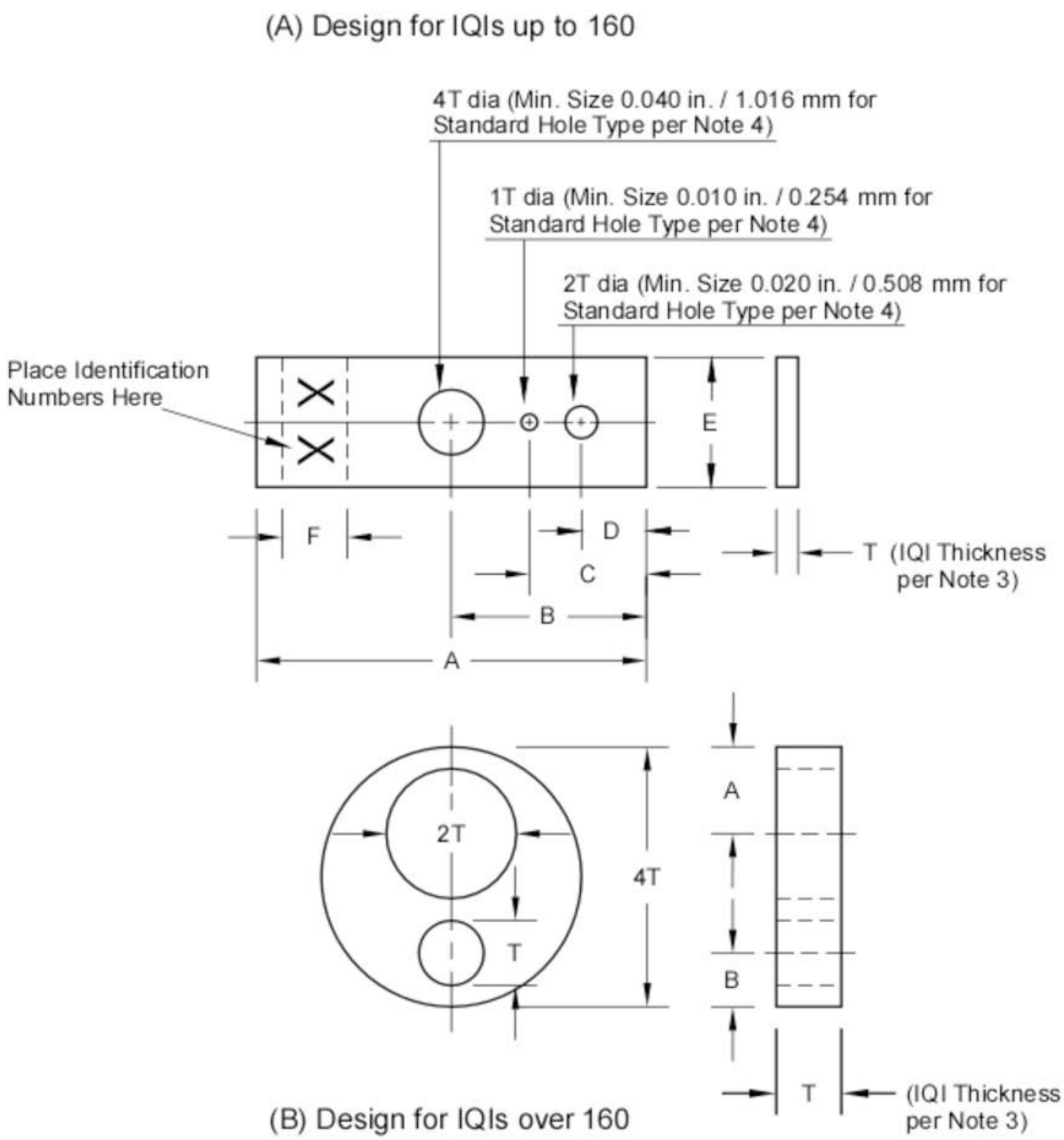
4.1.1 All image quality indicators (IQIs) shall be fabricated from materials or alloys identified or listed in accordance with 7.3. Other materials may be used in accordance with 7.4.

4.1.2 *Standard Hole-Type IQIs:*

4.1.2.1 Standard Hole-Type Image quality indicators (IQIs) shall dimensionally conform to the requirements of Fig. 1.

4.1.3 *Modified Hole-Type IQI:*

4.1.3.1 The rectangular IQI may be modified in length and width as necessary for special applications, provided the hole size(s) and IQI thickness conform to Fig. 1 or 4.1.4, as applicable.



NOTE 1—Tolerances for IQI thickness and hole diameter.

NOTE 2—Tolerances for True T-hole Diameter IQI thickness and hole diameter shall be ±10 %.

NOTE 3—*XX* identification number equals *T* in .001 inches.

NOTE 4—IQIs No. 1 through 9 for Standard Hole Type IQI's (4.1.2) are not 1*T*, 2*T*, and 4*T*.

NOTE 5—Holes shall be true and normal to the IQI. Do not chamfer.

Identification Number *T* (Note 3)	A in. (mm)	B in. (mm)	C in. (mm)	D in. (mm)	E in. (mm)	F in. (mm)	Tolerances (Note 2)
1–4	1.500 (38.1) ±0.015 (0.38)	0.750 (19.05) ±0.015 (0.38)	0.438 (11.13) ±0.015 (0.38)	0.250 (6.35) ±0.015 (0.38)	0.500 (12.7) ±0.015 (0.38)	0.250 (6.35) ±0.030 (0.76)	±10%
5–20	1.500 (38.1) ±0.015 (0.38)	0.750 (19.05) ±0.015 (0.38)	0.438 (11.13) ±0.015 (0.38)	0.250 (6.35) ±0.015 (0.38)	0.500 (12.7) ±0.015 (0.38)	0.250 (6.35) ±0.030 (0.76)	±0.0005 (0.127)
21–50	1.500 (38.1) ±0.015 (0.38)	0.750 (19.05) ±0.015 (0.38)	0.438 (11.13) ±0.015 (0.38)	0.250 (6.35) ±0.015 (0.38)	0.500 (12.7) ±0.015 (0.38)	0.250 (6.35) ±0.030 (0.76)	±0.0025 (0.635)
51–160	2.250 (57.15) ±0.030 (0.762)	1.375 (34.93) ±0.030 (0.762)	0.750 (19.05) ±0.030 (0.762)	0.375 (9.53) ±0.030 (0.762)	1.000 (25.4) ±0.030 (0.762)	0.375 (9.53) ±0.030 (0.762)	±0.005 (0.127)
Over 160	1.330T ±0.005 (0.127)	0.830T ±0.005 (0.127)	...	...	...	...	±0.010 (0.254)

FIG. 1 IQI Design

4.1.3.2 The IQI's shall be identified as specified in 4.1.5 to 4.1.5.2, as applicable, except that the identification numbers may be placed adjacent to the IQI if placement on the IQI is impractical.

4.1.3.3 When modified IQI's are used, details of the modification shall be documented in the records accompanying the examination results.

4.1.4 *True T-hole Diameter IQI:*

4.1.4.1 It may be desirable for non-film applications to use true T-hole diameter IQI's for numbers 1 through 9.

4.1.4.2 Hole sizes for true T-hole diameter IQI's may be made by using laser or an electric discharge machining (EDM) process and shall be within ±10 % of 1T, 2T and 4T (See Fig. 1, Note 3 for T)

4.1.4.3 When true T-hole-diameter IQI's are used, details of the modifications shall be documented in the records accompanying the examination results.

4.1.5 Both the rectangular and the circular IQIs shall be identified with number(s) made of lead or a material of similar radiation opacity. The number shall be bonded to the rectangular IQI's and shall be placed adjacent to circular IQI's to provide identification of the IQI on the image. The identification numbers shall indicate the thickness of the IQI in thousandths of an inch, that is, a number 10 IQI is 0.010 in. thick, a number 100 IQI is 0.100 in. thick, etc. Additional identification requirements are provided in 7.2.

4.1.5.1 *Alternative Identification Method*—It may be desirable for non-film applications to eliminate the lead number identifiers and replace them with either material addition or material removal methods as stated below:

(1) Material Addition Method—Numbers may be made of the same material as that of the IQI and of sufficient thickness to be clearly discernable within the radiologic image.

(2) Material Removal Method—Numbers may be cut into the IQI in such a manner as to be clearly discernable in the radiologic image. Processes such as laser etching, chemical etching, precision stamping, etc., may be used to create the numbers within the IQI.

4.1.5.2 Alloy-group identification shall be in accordance with 7.2. Rectangular IQI's shall be notched as shown in Fig. 2, except the corner notch for Group 001 is at a 45 degree angle. Round IQI's shall be vibrotooled or etched as shown in Fig. 3.

4.1.5.3 True T-hole diameter IQI identification numbers shall be rotated 90° as compared to Standard Hole Type IQIs. See Fig. 4.

5. IQI Procurement

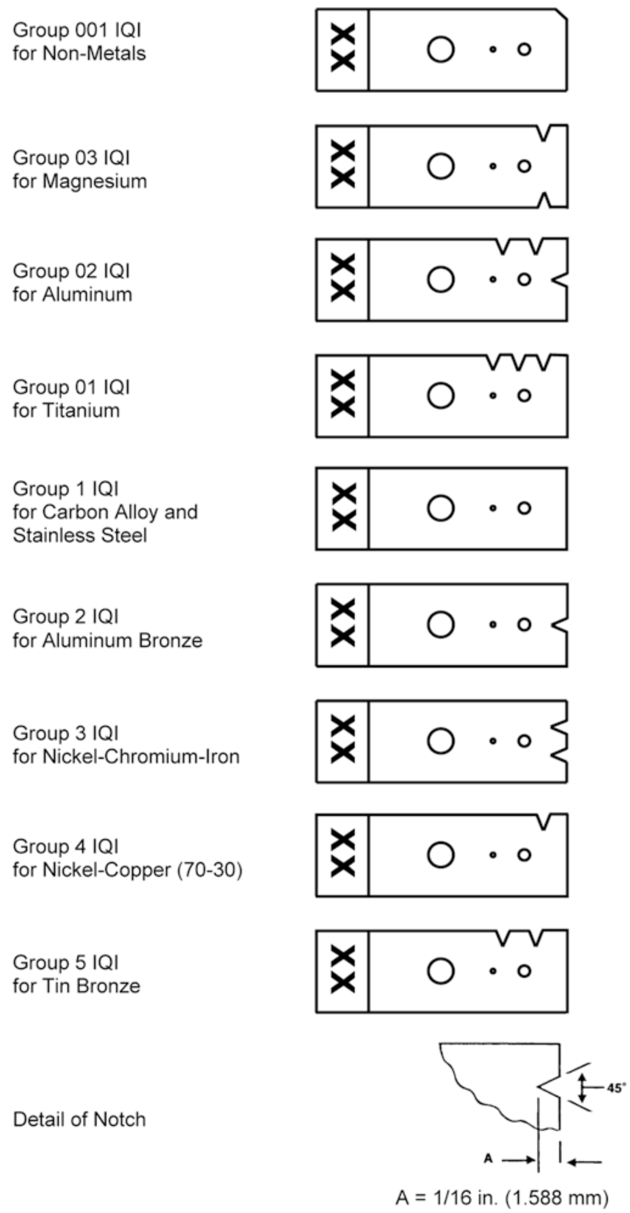
5.1 When selecting IQI's for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Determine the Image Quality Level requirements as described in Section 6 and Table 1.

5.1.4 Select the applicable IQI's that represent the required IQI thickness and alloy(s).



NOTCH TOLERANCES
Width +15°
−0°
(A) Depth +1⁄16 in. (1.588mm)
−1⁄32 in. (0.794 mm)

FIG. 2 Rectangular IQI Notch Identification and Material Grouping

NOTE 1—This practice does not recommend or suggest specific IQI sets to be procured. Section 5 is an aid in selecting IQI's based on specific needs.

6. Image Quality Levels

6.1 Image quality levels are designated by a two part expression; *X-YT*. The first part of the expression, *X*, refers to the IQI thickness expressed as a percentage of the specimen thickness. The second part of the expression, *YT*, refers to the diameter of the required hole and is expressed as a multiple of

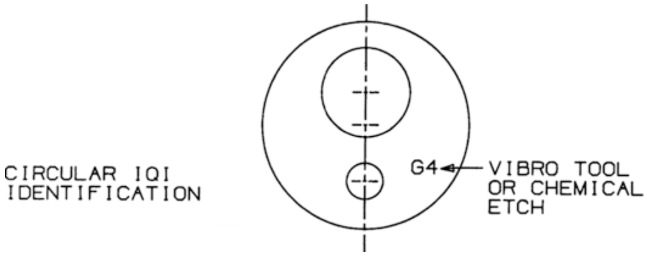


FIG. 3 Circular IQI Identification

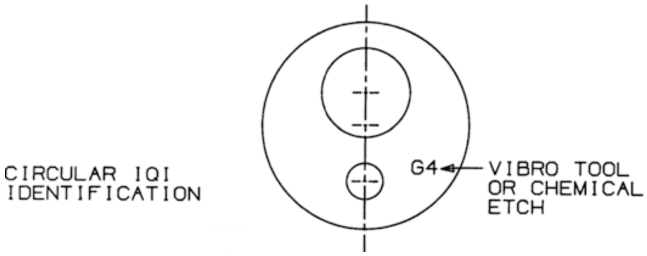


FIG. 4 True T-hole Diameter Type IQI Identification Orientation

the IQI thickness, *T* (for example, the image quality level 2-2*T* means that the IQI thickness, *T*, is no more than 2 % of the specimen thickness and that the diameter of the required IQI hole is 2 × *T*).

NOTE 2—Standard Hole Type Image Quality Indicators (IQI's) less than number 10 have hole sizes 0.010, 0.020, and 0.040 in. diameter regardless of the IQI thickness. Therefore, Standard Hole Type IQI's less than number 10 do not represent the quality levels specified in 6.1 and Table 1. The equivalent IQI sensitivity (EPS) can be calculated using the equation in Appendix X1.

6.2 Typical image quality level designations are shown in Table 1. The level of inspection specified should be based on service requirements of the product. Care should be taken in specifying True T-hole Diameter Type IQI's (4.1.4) and/or image quality levels 2-1*T*, 1-1*T*, and 1-2*T* by first determining that these levels can be maintained in production.

6.3 In specifying image quality levels, the contract, purchase order, product specification, or drawing should state the proper two-part expression and clearly indicate the thickness of the material to which the level refers. In place of a designated two–part expression, the IQI number and minimum discernible hole size shall be specified.

6.4 Appendix X1 of this practice provides a method for determining equivalent IQI sensitivity (EPS) in percent. Under certain conditions (as described within the purchaser-supplier agreement), EPS may be useful in relating a discernible hole size of the IQI thickness with the section thickness radiographed for establishing an overall technical image quality equivalency. This is not an alternative IQI provision for the originally specified IQI requirement of this practice, but may be a useful tool for establishing technical image equivalency on a case basis need with specific customer approvals.

6.5 Practice E747 contains provisions for wire IQI's that use varying length and diameter wires to effect image quality requirements. The requirements of Practice E747 are different from this standard; however, Practice E747 (see Table 4) contains provisions whereby wire sizes equivalent to corresponding 1T, 2T and 4T holes for various plaque thicknesses are provided. Appendix X1 of Practice E747 also provides methods for determining equivalencies between wire and hole type IQI's. This is not an alternative IQI provision for the originally specified IQI requirements of this practice, but may be useful for establishing technical image equivalency on a case basis need with specific customer approvals.

TABLE 1 Typical Image Quality Levels

Image Quality Levels	IQI Thickness	Minimum Perceptible Hole Diameter	Equivalent IQI Sensitivity, %[A]
Standard Image Quality Levels			
2-1*T*	1/50 (2 %) of Specimen Thickness	1*T*	1.4
2-2*T*[B]		2*T*	2.0
2-4*T*		4*T*	2.8
Special Image Quality Levels			
1-1*T*	1/100 (1 %) of Specimen Thickness	1*T*	0.7
1-2*T*		2*T*	1
4-2*T*	1/25 (4 %) of Specimen Thickness	2*T*	4

[A] Equivalent IQI sensitivity is that thickness of the IQI, expressed as a percentage of the part thickness, in which the 2*T* hole would be visible under the same conditions.
[B] For *Level* 2-2*T* *Radiologic*—The 2*T* hole in an IQI, 1/50 (2 %) of the specimen thickness, is visible.

6.6 Test Methods E746 and E1735 provide additional tools for determining relative image quality response of industrial radiological systems when exposed to energy levels described within those test methods. Both of these test methods use the "equivalent penetrameter sensitivity" (EPS) concept to provide statistical image quality information that allows the imaging system or other exposure components to be assessed on a relative basis. These test methods are not alternative IQI provisions for the originally specified IQI requirements of this practice, but may be useful on a case basis with specific customer approvals, for establishing technical image equivalency of certain aspects of the radiological imaging process.

7. Material Groups

7.1 *General:*

7.1.1 Materials have been designated in nine groups based on their radiation absorption characteristics: Group 001 for non-metals. Groups 03, 02, and 01 for light metals and Groups 1 through 5 for heavy metals.

7.1.2 The non-metals group, typically in the form of fiber-reinforced phenolic resin, are identified as 001 since these materials have the least radiation absorption of all the material groups.

7.1.3 The light metal groups, magnesium (Mg), aluminum (A1), and titanium (Ti) are identified 03, 02, and 01 respectively for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.4 The heavy metal groups, steel, copper base, nickel base, and kindred alloys are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

NOTE 3—The metals groups were established experimentally at 180 kV on ¾-in. (19-mm) thick specimens. They apply from 125 kV to the multivolt range. The non-metal group was established experimentally at a range of 15 to 60 kV on 0.100-in to 0.250-in (2.54-mm to 6.35-mm) thick specimens using MIL-I-24768 thermosetting plastic laminated insulation materials type FBE and FBG.

7.1.5 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.6 The materials from which the IQI for the group are to be made are designated in each case, and these IQI's are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 *Identification System:*

7.2.1 A notching system has been designated for the nine materials groups of IQI's and is shown in Fig. 2 for rectangular IQI's.

7.2.2 For circular IQI's, a group designation shall be vibro-tooled or etched on the IQI to identify it by using the letter "G" followed by the group number, for example, G4 for a Group 4 IQI. For identification of the group on the image, corresponding lead characters shall be placed adjacent to the circular IQI, just as is done with the lead numbers identifying the thickness. An identification example is shown in Fig. 3.

7.3 *Materials Groups:*

7.3.1 *Materials Group 001:*

7.3.1.1 Image quality indicators (IQI's) may be made from phenolic resin laminate materials specified in MIL-I-24768, or any of the materials listed in Practice E2662.

7.3.1.2 Use on polymer matrix composite materials or other low density non-metal materials at low energies, typically below 50 kV.

7.3.2 *Materials Group* 03:

7.3.2.1 Image quality indicators (IQI's) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

7.3.2.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.3.3 *Materials Group* 02:

7.3.3.1 Image quality indicators (IQI's) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.3.3.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.3.4 *Materials Group* 01:

7.3.4.1 Image quality indicators (IQI's) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.3.4.2 Use on all alloys of which titanium is the predominant alloying constituent.

7.3.5 *Materials Group* 1:

7.3.5.1 Image quality indicators (IQI's) shall be made of carbon steel or Type 300 series stainless steel.

7.3.5.2 Use on all carbon steel, all low-alloy steels, all stainless steels, manganese-nickel-aluminum bronze (Superston).

7.3.6 *Materials Group* 2:

7.3.6.1 Image quality indicators (IQI's) shall be made of aluminum bronze (Specification B150/B150M).

7.3.6.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

7.3.7 *Materials Group* 3:

7.3.7.1 Image quality indicators (IQI's) shall be made of nickel-chromium-iron alloy (UNS No. NO6600) (Inconel). (Specification B166.)

7.3.7.2 Use on nickel-chromium-iron alloy and 18 % nickel-maraging steel.

7.3.8 *Materials Group* 4:

7.3.8.1 Image quality indicators (IQI's) shall be made of 70 to 30 nickel-copper alloy (Monel) (Specification B164) or equivalent.

7.3.8.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQI's may be used on the leaded brasses, since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.3.9 *Materials Group* 5:

7.3.9.1 Image quality indicators (IQI's) shall be made of phosphor bronze (Specification B139/B139M).

7.3.9.2 Use on bronzes including gun-metal and valve bronze, leaded-tin bronze of higher lead content than valve bronze. Group 5 IQI's may be used on bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 4—In developing the nine listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(1) Group 2—Haynes Alloy IN-100.

(2) Group 3—Haynes Alloy No. 713C, Hastelloy D, G.E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93, Inconel X, Inconel 718, and Haynes Stellite Alloy NO. S-816.

(3) Group 4—Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(4) Group 5—Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. IQIs of any of these materials are considered applicable for the materials that follow it.

(5) Group 001—Garolite

NOTE 5—The committee formulating these recommendations, recommended other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

7.4 *Radiologically Similar IQI Materials:*

7.4.1 For materials not herein covered, IQI's of radiographically similar materials may be used when the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production radiography. Film density readings shall be between 2.0 and

4.0 for both materials. If the film density of the material to be radiographed is within the range of 0 to +15 % of the IQI material, the IQI material shall be considered radiographically similar and may be used to fabricate IQI's for examination of the production material.

7.4.1.1 Radiological similarity tests may be performed with non-film radiological systems, however, the minimum and maximum pixel values for both materials shall be within the range established for production examinations.

7.4.2 It shall always be permissible to use IQI's of radiologically less dense material than the subject material being examined.

8. IQI Certification

8.1 Records shall be available that attest to the conformance of the material type, grouping (notches), and dimensional tolerances of the IQI's specified by this practice.

9. Precision and Bias

9.1 *Precision and Bias*—No statement is made about the precision or bias for indicating the quality of radiological images since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

APPENDIX

(Nonmandatory Information)

X1. EQUIVALENT IQI (PENETRAMETER) SENSITIVITY (EPS)

X1.1 To find the equivalent IQI sensitivity (percent), the hole size (diameter in inches), of the IQI thickness (inches), for a section thickness (inches), the following equation may be used:

where:

$$\alpha = \frac{100}{X}\sqrt{\frac{TH}{2}},$$

α = equivalent IQI sensitivity, %,
X = section thickness to be examined, in.,
T = IQI Thickness, in., and
H = hole diameter, in.

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STANDARD PRACTICE FOR RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

(19) SE-1030/SE-1030M

(Identical with ASTM Specification E1030/E1030M-15.)

Standard Practice for Radiographic Examination of Metallic Castings

1. Scope

1.1 This practice provides a uniform procedure for radiographic examination of metallic castings using radiographic film as the recording medium.

1.2 This standard addresses the achievement of, or protocols for achieving, common or practical levels of radiographic coverage for castings, to detect primarily volumetric discontinuities to sensitivity levels measured by nominated image quality indicators. All departures, including alternate means or methods to increase coverage, or address challenges of detecting non-volumetric planar-type discontinuities, shall be agreed upon between the purchaser and supplier and shall consider Appendix X1 and Appendix X2.

1.3 The radiographic techniques stated herein provide adequate assurance for defect detectability; however, it is recognized that, for special applications, specific techniques using more or less stringent requirements may be required than those specified. In these cases, the use of alternate radiographic techniques shall be as agreed upon between purchaser and supplier (also see Section 5).

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E94 Guide for Radiographic Examination
E155 Reference Radiographs for Inspection of Aluminum and Magnesium Castings
E186 Reference Radiographs for Heavy-Walled (2 to 4½ in. (50.8 to 114 mm)) Steel Castings
E192 Reference Radiographs of Investment Steel Castings for Aerospace Applications
E272 Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
E280 Reference Radiographs for Heavy-Walled (4½ to 12 in. (114 to 305 mm)) Steel Castings
E310 Reference Radiographs for Tin Bronze Castings
E446 Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness
E505 Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings
E543 Specification for Agencies Performing Nondestructive Testing
E689 Reference Radiographs for Ductile Iron Castings
E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
E802 Reference Radiographs for Gray Iron Castings Up to 4½ in. (114 mm) in Thickness
E999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E1079 Practice for Calibration of Transmission Densitometers
E1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films
E1316 Terminology for Nondestructive Examinations

E1320 Reference Radiographs for Titanium Castings
E1742 Practice for Radiographic Examination
E1815 Test Method for Classification of Film Systems for Industrial Radiography

2.2 *ASNT/ANSI Standards:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing
CP-189 Qualification and Certification of Nondestructive Testing Personnel

2.3 *Other Standards:*

NAS 410 National Aerospace Standard Certification and Qualification of Nondestructive Test Personnel

2.4 *ISO Standards:*

ISO 5579 Non-Destructive Testing—Radiographic Testing of Metallic Materials Using Film and X- or Gamma-rays—Basic Rules
ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E1316.

4. Significance and Use

4.1 The requirements expressed in this practice are intended to control the quality of the radiographic images, to produce satisfactory and consistent results, and are not intended for controlling the acceptability or quality of materials or products.

5. Basis of Application

5.1 The following items shall be agreed upon by the purchaser and supplier:

5.1.1 *Nondestructive Testing Agency Evaluation*—If specified in the contractual agreement, nondestructive testing (NDT) agencies shall be qualified and evaluated in accordance with Practice E543. The applicable version of Practice E543 shall be specified in the contractual agreement.

5.1.2 *Personnel Qualification*—Personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS 410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.1.3 *Apparatus*—General requirements (see 6.1 through 6.9) shall be specified.

5.1.4 *Requirements*—General requirements (see 8.1, 8.2, 8.5, and 8.7.4) shall be specified.

5.1.5 Procedure Requirements (see 9.1, 9.1.1, 9.3, 9.7.4, and 9.7.7) shall be specified.

5.1.6 *Records*—Record retention (see 12.1) shall be specified.

6. Apparatus

6.1 *Radiation Sources:*

6.1.1 *X Radiation Sources*—Selection of appropriate X-ray voltage and current levels is dependent upon variables regarding the specimen being examined (material type and thickness) and economically permissible exposure time. The suitability of these X-ray parameters shall be demonstrated by attainment of required penetrameter (IQI) sensitivity and compliance with all other requirements stipulated herein. Guide E94 contains provisions concerning exposure calculations and charts for the use of X-ray sources.

6.1.2 *Gamma Radiation Sources*—Isotope sources, when used, shall be capable of demonstrating the required radiographic sensitivity.

6.2 *Film Holders and Cassettes*—Film holders and cassettes shall be light-tight and shall be handled properly to reduce the likelihood that they may be damaged. They may be flexible vinyl, plastic, or any durable material; or, they may be made from metallic materials. In the event that light leaks into the film holder and produces images on the film extending into the area of interest, the film shall be rejected. If the film holder exhibits light leaks, it shall be repaired before reuse or discarded. Film holders and cassettes should be routinely examined to minimize the likelihood of light leaks.

6.3 *Intensifying Screens:*

6.3.1 *Lead-Foil Screens:*

6.3.1.1 Intensifying screens of the lead-foil type are generally used for all production radiography. Lead-foil screens shall be of the same approximate area dimensions as the film being used and they shall be in direct contact with the film during exposure.

6.3.1.2 Recommended screen thicknesses are listed in Table 1 for the applicable voltage range being used.

6.3.1.3 Sheet lead, with or without backing, used for screens should be visually examined for dust, dirt, oxidation, cracking or creasing, foreign material or other condition that could render undesirable nonrelevant images on the film.

6.3.2 *Fluorescent, Fluorometallic, or Other Metallic Screens:*

6.3.2.1 Fluorescent, fluorometallic, or other metallic screens may be used. However, they must be capable of demonstrating the required penetrameter (IQI) sensitivity. Fluorescent or fluorometallic screens may cause limitations in image quality (see Guide E94, Appendix X1.)

6.3.2.2 *Screen Care*—All screens should be handled carefully to avoid dents, scratches, grease, or dirt on active surfaces. Screens that render false indications on radiographs shall be discarded or reworked to eliminate the artifact.

6.3.3 *Other Screens*—International Standard ISO 5579 contains similar provisions for intensifying screens as this practice. International users of these type screens who prefer the use of

TABLE 1 Lead Foil Screens[A]

Energy Range/Isotope	Front Screen, in.[A]	Back Screen Minimum, in.	Front and Back Screens, mm[B]
0 to 150 keV[C]	0.000 to 0.001	0.005[D]	0 to 0.15
151 to 200 keV	0.000 to 0.005	0.005[D]	0 to 0.15
201 to 320 keV	0.001 to 0.010	0.005	0.02 to 0.2
Se-75	0.001 to 0.010	0.005	0.1 to 0.2
321 to 450 keV	0.05 to 0.015	0.010	0.1 to 0.2
Ir-192	0.05 to 0.015	0.010	0.02 to 0.2
451 keV to 2 MeV	0.05 to 0.020	0.010	0.1 to 0.5
Co-60	0.05 to 0.020	0.010	0.1 to 0.5
2 to 4 MeV	0.010 to 0.020	0.010	0.1 to 0.5
4 to 10 MeV	0.010 to 0.030	0.010	0.5 to 1.0
10 to 25 MeV	0.010 to 0.050	0.010	1.0 to 2.0

[A]The lead screen thickness listed for the various voltage ranges are recommended thicknesses and not required thicknesses. Other thicknesses and materials may be used provided the required radiographic quality level, contrast, and density are achieved.
[B]Lead screen thicknesses in accordance with ISO 5579 in SI units. For energy ranges of Co-60 and 451 keV to 4 MeV, steel or copper screens of 0.1 to 0.5 mm may be used. For energy ranges above 4 MeV to 10 MeV, 0.5 to 1.0 mm steel or copper or up to 0.5 mm tantalum screens are recommended. Additional back scatter shielding may be achieved by additional lead screen behind the cassettes.
[C]Prepacked film with lead screens may be used from 80 to 150 keV. No lead screens are recommended below 80 keV. Prepackaged film may be used at higher energy levels provided the contrast, density, radiographic quality level, and backscatter requirements are achieved. Additional intermediate lead screens may be used for reduction of scattered radiation at higher energies.
[D]No back screen is required provided the backscatter requirements of 9.5 are met.

ISO 5579 for their particular applications should specify such alternate provisions within separate contractual arrangements from this practice.

6.4 *Filters*—Filters shall be used whenever the contrast reductions caused by low-energy scattered radiation or the extent of undercut and edge burn-off occurring on production radiographs is of significant magnitude so as to cause failure to meet the quality level or radiographic coverage requirements stipulated by the job order or contract (see Guide E94).

6.5 *Masking*—Masking material may be used, as necessary, to help reduce image degradation due to undercutting (see Guide E94).

6.6 *Penetrameters (IQI)*—Unless otherwise specified by the applicable job order or contract, only those penetrameters that comply with the design and identification requirements specified in Practices E747, E1025, or E1742 shall be used.

6.7 *Shims and Separate Blocks*—Shims or separate blocks made of the same or radiographically similar materials (as defined in Practice E1025) may be used to facilitate penetrameter positioning. There is no restriction on shim or separate block thickness provided the penetrameter and area-of-interest density tolerance requirements of 9.7.6.2 are met.

6.8 *Radiographic Location and Identification Markers*—Lead numbers and letters are used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radiographic technique to image the markers on the radiograph. As a general rule, markers 1⁄16-in. [1.5-mm] thick will suffice for most low-energy (less than 1 MeV) X-ray and Iridium-192 radiography; for higher-energy radiography it may be necessary to use markers that are 1⁄8-in. [3.0-mm] or more thick.

6.9 *Radiographic Density Measurement Apparatus*—Either a transmission densitometer or a step-wedge comparison film shall be used for judging film density requirements. Step wedge comparison films or densitometer calibration, or both, shall be verified by comparison with a calibrated step-wedge film traceable to the National Institute of Standards and Technology. Densitometers shall be calibrated in accordance with Practice E1079.

7. Reagents and Materials

7.1 *Film Systems*—Only film systems having cognizant engineering organization (CEO) approval or meeting the requirements of Test Method E1815 shall be used to meet the requirements of this practice.

8. Requirements

8.1 *Procedure Requirement*—Unless otherwise specified by the applicable job order or contract, radiographic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of written procedures shall be dictated by a purchaser and supplier agreement. The procedure details should include at least those items stipulated in Appendix X1. In addition, a radiographic standard shooting sketch (RSS), Fig. X1.1, shall be prepared similar to that shown in Appendix X1 and shall be available for review during interpretation of the film.

8.2 *Radiographic Coverage*—Unless otherwise specified by a purchaser and supplier agreement, the extent of radiographic coverage shall be the maximum practical volume of the casting. Areas that require radiography shall be designated as illustrated in Figs. X1.2 and X1.3 of Appendix X1. When the shape or configuration of the casting is such that radiography is impractical, these areas shall be so designated on drawings or sketches that accompany the radiographs. Examples of casting geometries and configurations that may be considered impractical to radiograph are illustrated in Appendix X2.

8.3 *Radiographic Film Quality*—All radiographs shall be free of mechanical, chemical, handling-related, or other blemishes which could mask or be confused with the image of any discontinuity in the area of interest on the radiograph. If any doubt exists as to the true nature of an indication exhibited by the film, the radiograph shall be retaken or rejected.

8.4 *Radiographic Quality Level*—The applicable job order or contract shall dictate the requirements for radiographic quality level. (See Practice E1025 or Practice E747 for guidance in selection of quality level.)

8.5 *Acceptance Level*—Radiographic acceptance levels and associated severity levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.6 *Radiographic Density Limitations*—Radiographic density in the area of interest shall be within 1.5 to 4.0 for either single or superimposed viewing.

8.7 *Film Handling:*

8.7.1 *Darkroom Facilities*—Darkroom facilities should be kept clean and as dust-free as practical. Safelights should be those recommended by film manufacturers for the radiographic materials used and should be positioned in accordance with the manufacturer's recommendations. All darkroom equipment and materials should be capable of producing radiographs that are suitable for interpretation.

8.7.2 *Film Processing*—Guide E999 should be consulted for guidance on film processing.

8.7.3 *Film Viewing Facilities*—Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. The viewing light shall be of sufficient intensity to review densities up to 4.0 and be appropriately controlled so that the optimum intensity for single or superimposed viewing of radiographs may be selected.

8.7.4 *Storage of Radiographs*—When storage is required by the applicable job order or contract, the radiographs should be stored in an area with sufficient environmental control to preclude image deterioration or other damage. The radiograph storage duration and location after casting delivery shall be as agreed upon between purchaser and supplier. (See Guide E1254 for storage information.)

9. Procedure

9.1 *Time of Examination*—Unless otherwise specified by the applicable job order or contract, radiography may be performed prior to heat treatment and in the as-cast, rough-machined, or finished-machined condition.

9.1.1 *Penetrameter (IQI) Selection*—Unless otherwise specified in the applicable job order or contract, penetrameter (IQI) selection shall be based on the following: if the thickness to be radiographed exceeds the design thickness of the finished piece, the penetrameter (IQI) size shall be based on a thickness which does not exceed the design thickness of the finished piece by more than 20 % or ¼ in. [6.35 mm], whichever is greater. In no case shall the penetrameter (IQI) size be based on a thickness greater than the thickness to be radiographed.

9.2 *Surface Preparation*—The casting surfaces shall be prepared as necessary to remove any conditions that could mask or be confused with internal casting discontinuities.

9.3 *Source-to-Film Distance*—Unless otherwise specified in the applicable job order or contract, geometric unsharpness (Ug) shall not exceed the following in Table 2. The user should be aware that exposures utilizing the maximum geometric unsharpness permitted by Table 2 may not produce acceptable sensitivity and the unsharpness should be reduced in order to achieve the required sensitivity.

9.4 *Direction of Radiation*—The direction of radiation shall be governed by the geometry of the casting and the radiographic coverage and quality requirements stipulated by the applicable job order or contract. Whenever practicable, place the central beam of the radiation perpendicular to the surface of the film. Appendix X2 provides examples of preferred source and film orientations and examples of casting geometries and configurations on which radiography is impractical or very difficult.

9.5 *Back-Scattered Radiation Protection:*

9.5.1 *Back-Scattered Radiation*—(secondary radiation emanating from surfaces behind the film, that is, walls, floors, etc.) serves to reduce radiographic contrast and may produce undesirable effects on radiographic quality. A ⅛-in. (3.2-mm) lead sheet placed behind the film generally furnishes adequate protection against back-scattered radiation.

9.5.2 To detect back-scattered radiation, position a lead letter "B" (approximately ⅛-in. [3.2-mm] thick by ½-in. [12.5-mm] high) on the rear side of the film holder. If a light image (lower density) of the lead letter "B" appears on the radiograph, it indicates that more back-scatter protection is necessary. The appearance of a dark image of the lead letter "B" should be disregarded unless the dark image could mask or be confused with rejectable casting defects.

9.6 *Penetrameter (IQI) Placement*—Place all penetrameters (IQI) being radiographed on the source side of the casting. Place penetrameters (IQI) in the radiographic area of interest, unless the use of a shim or separate block is necessary, as specified in 9.7.6.

9.7 *Number of Penetrameters (IQI):*

9.7.1 One penetrameter (IQI) shall represent an area within which radiographic densities do not vary more than +30 % to –15 % from the density measured through the body of the penetrameter (IQI).

TABLE 2 Unsharpness (Ug) Maximum

Material Thickness	Ug Maximum[A]
Under 1 in. [25.4 mm]	0.010 in. [0.25 mm]
1 through 2 in. [25.4 through 51 mm]	0.020 in. [0.50 mm]
Over 2 through 3 in. [over 51 through 76.0 mm]	0.030 in. [0.76 mm]
Over 3 through 4 in. [over 76.0 through 100 mm]	0.040 in. [1.00 mm]
Greater than 4 in. [greater than 100 mm]	0.070 in. [1.78 mm][B]

[A] Geometric unsharpness values shall be determined (calculated) as specified by the formula in Guide E94.
[B] The geometric unsharpness should be reduced to 0.050 in. [1.27 mm] if the required IQI sensitivity is not achieved.

9.7.2 When the film density varies more than –15 % to +30 %, two penetrameters (IQI) shall be used as follows: if one penetrameter (IQI) shows acceptable sensitivity representing the most dense portion of the exposure, and the second penetrameter (IQI) shows acceptable sensitivity representing the least dense portion of the exposure, then these two penetrameters (IQI) shall qualify the exposure location within these densities, provided the density requirements stipulated in 8.6 are met.

9.7.3 For cylindrical or flat castings where more than one film holder is used for an exposure, at least one penetrameter (IQI) image shall appear on each radiograph. For cylindrical shapes, where a panoramic type source of radiation is placed in the center of the cylinder and a complete or partial circumference is radiographed using at least four overlapped film holders, at least three penetrameters (IQI) shall be used. On partial circumference exposures, a penetrameter (IQI) shall be placed at each end of the length of the image to be evaluated on the radiograph with the intermediate penetrameters (IQI) placed at equal divisions of the length covered. For full circumferential coverage, three penetrameters (IQI) spaced 120° apart shall be used, even when using a single length of roll film.

9.7.4 When an array of individual castings in a circle is radiographed, the requirements of 9.7.1 or 9.7.2, or both, shall prevail for each casting.

9.7.5 If the required penetrameter (IQI) sensitivity does not show on any one film in a multiple film technique (see 9.11), but does show in composite (superimposed) film viewing, interpretation shall be permitted only by composite film viewing for the respective area.

9.7.6 When it is not practicable to place the penetrameter(s) (IQI) on the casting, a shim or separate block conforming to the requirements of 6.7 may be used.

9.7.6.1 The penetrameter (IQI) shall be no closer to the film than the source side of that part of the casting being radiographed in the current view.

9.7.6.2 The radiographic density measured adjacent to the penetrameter (IQI) through the body of the shim or separate block shall not exceed the density measured in the area of interest by more than 15 %. The density may be lighter than the area of interest density, provided acceptable quality level is obtained and the density requirements of 8.6 are met.

9.7.6.3 The shim or separate block shall be placed at the corner of the film holder or close to that part of the area of interest that is furthest from the central beam. This is the worst case position from a beam angle standpoint that a discontinuity would be in.

9.7.6.4 The shim or separate block dimensions shall exceed the penetrameter (IQI) dimensions such that the outline of at least three sides of the penetrameter (IQI) image shall be visible on the radiograph.

9.7.7 *Film Side Penetrameter (IQI)*—In the case where the penetrameter (IQI) cannot be physically placed on the source side and the use of a separate block technique is not practical, penetrameters (IQI) placed on the film side may be used. The applicable job order or contract shall dictate the requirements for film side radiographic quality level (see 8.4).

9.8 *Location Markers*—The radiographic image of the location markers for the coordination of the casting with the film shall appear on the film, without interfering with the interpretation, in such an arrangement that it is evident that the required coverage was obtained. These marker positions shall be marked on the casting and the position of the markers shall be maintained on the part during the complete radiographic cycle. The RSS shall show all marker locations.

9.9 *Radiographic Identification*—A system of positive identification of the film shall be used and each film shall have a unique identification relating it to the item being examined. As a minimum, the following additional information shall appear on each radiograph or in the records accompanying each radiograph:

(1) Identification of organization making the radiograph,

(2) Date of exposure,

(3) Identification of the part, component or system and, where applicable, the weld joint in the component or system, and

(4) Whether the radiograph is an original or repaired area.

9.10 *Subsequent Exposure Identification*— All repair radiographs after the original (initial) shall have an examination status designation that indicates the reason. Subsequent radiographs made by reason of a repaired area shall be identified with the letter "R" followed by the respective repair cycle (that is, R-1 for the first repair, R-2 for the second repair, etc.). Subsequent radiographs that are necessary as a result of additional surface preparation should be identified by the letters "REG."

9.11 *Multiple Film Techniques*—Two or more films of equal or different speeds in the same cassette are allowed, provided prescribed quality level and density requirements are met (see 9.7.2 and 9.7.5).

9.12 *Radiographic Techniques:*

9.12.1 *Single Wall Technique*—Except as provided in 9.12.2 or 9.12.3, radiography shall be performed using a technique in which the radiation passes through only one wall.

9.12.2 *Double Wall Technique with I.D. of 4 in. [100 mm] and Less*—For castings with an inside diameter of 4 in. [100 mm] or less, a technique may be used in which the radiation passes through both walls and both walls are viewed for acceptance on the same film. An adequate number of exposures shall be taken to ensure that required coverage has been obtained.

9.12.3 *Double Wall Technique with I.D. of Over 4 in. [100 mm]*—For castings with an inside diameter greater than 4 in. [100mm], a technique may be used in which the radiation passes through both walls but only the wall closest to the film is being examined for acceptance. In this instance, the IQI(s) shall be positioned such that their distance from the film is comparable to the film-to-object distance of the object being examined.

9.13 **Safety—**Radiographic procedures shall comply with applicable city, state, and federal regulations.

10. Radiograph Evaluation

10.1 **Film Quality**—Verify that the radiograph meets the quality requirements specified in 8.3, 8.4, 8.6, 9.5.2 and 9.7.

10.2 **Film Evaluation**—Determine the acceptance or rejection of the casting by comparing the radiographic image to the agreed upon acceptance criteria (see 8.5) based on the actual casting thickness in which the flaw resides.

11. Reference Radiographs

11.1 Reference Radiographs E155, E186, E192, E272, E280, E310, E446, E505, E689, E802, and E1320 are graded radiographic illustrations of various casting discontinuities. These reference radiographs may be used to help establish acceptance criteria and may also be useful as radiographic interpretation training aids.

12. Report

12.1 The following radiographic records shall be maintained as agreed upon between purchaser and supplier:

12.1.1 Radiographic standard shooting sketch,

12.1.2 Weld repair documentation,

12.1.3 Film,

12.1.4 Film interpretation record containing as a minimum:

12.1.4.1 Disposition of each radiograph (acceptable or rejectable),

12.1.4.2 If rejectable, cause for rejection (shrink, gas, etc.),

12.1.4.3 Surface indication verified by visual examination (mold, marks, etc.), and

12.1.4.4 Signature of the film interpreter.

13. Keywords

13.1 castings; gamma-ray; nondestructive testing; radiographic; radiography; X-ray

APPENDIXES

(Nonmandatory Information)

X1. RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

X1.1 The radiographic standard shooting sketch (RSS) provides the radiographic operator and the radiographic interpreter with pertinent information regarding the examination of a casting. The RSS is designed to standardize radiographic methodologies associated with casting examination; it may also provide a means of a purchaser and supplier agreement, prior to initiation of the examination on a production basis. The use of a RSS is advantageous due to the many configurations associated with castings and the corresponding variations in techniques for examination of any particular one. The RSS provides a map of location marker placement, directions for source and film arrangement, and instructions for all other parameters associated with radiography of a casting. This information serves to provide the most efficient method for controlling the quality and consistency of the resultant radiographic representations.

X1.2 The RSS usually consists of an instruction sheet and sketch(es) of the casting: the instruction sheet specifies the radiographic equipment, materials, and technique-acceptance parameters for each location; the sketch(es) illustrate(s) the location, orientation, and the source and film arrangement for each location. Figs. X1.1-X1.3 of this appendix provide a typical instruction sheet and sketch sheets. As a minimum, the RSS should provide the following information. All spaces shall be filled in unless not applicable; in those cases, the space shall be marked NA.

X1.2.1 The instruction sheet should provide the following:

X1.2.1.1 Company preparing RSS and activity performing radiography.

X1.2.1.2 Casting identification including:

(1) Drawing number,

(2) Casting identification number,

(3) Descriptive name (for example, pump casting, valve body, etc.),

(4) Material type and material specification,

(5) Heat number, and

(6) Pattern number.

X1.2.1.3 Surface condition at time of radiography (as cast, rough machined, finished machined).

X1.2.1.4 Spaces for approval (as applicable).

X1.2.1.5 *Radiographic Technique Parameters for Each Location:*

(1) Radiographic location designation,

(2) Source type and size,

(3) Finished thickness,

(4) Thickness when radiographed,

(5) Penetrameters,

(6) Source to film distance,

(7) Film type and quantity,

(8) Film size,

(9) Required penetrameter (IQI) quality level,

(10) Radiographic acceptance standard, and

(11) Applicable radiographic severity level.

X1.2.2 The sketch(es) should provide the following:

X1.2.2.1 Location marker placement.

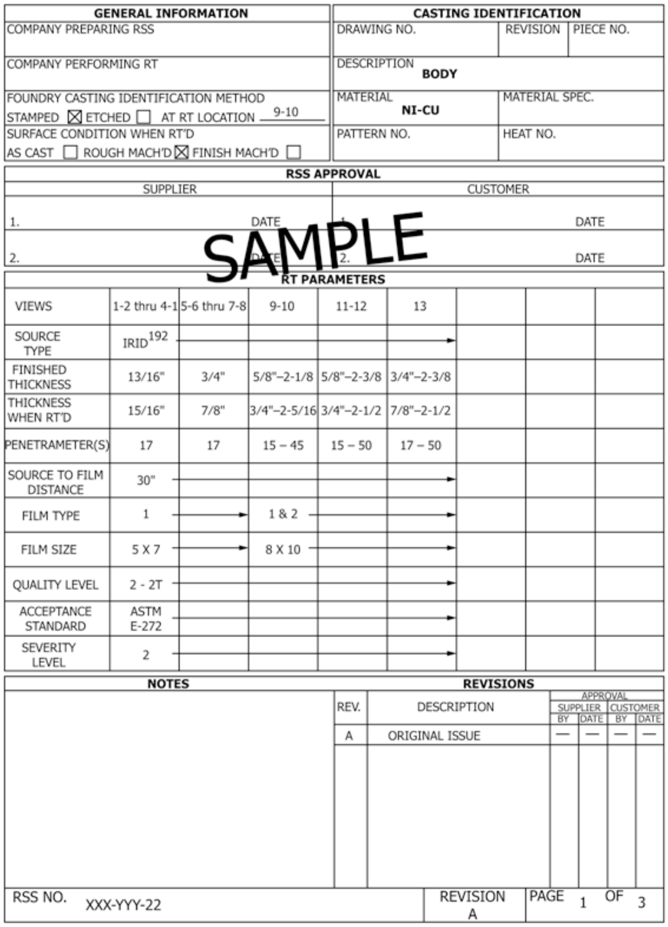
X1.2.2.2 Location of foundry's identification pad or symbol on the casting.

X1.2.2.3 Designation of areas that require radiography (as applicable).

X1.2.2.4 Designation of areas that are considered impractical or very difficult to radiograph (see 1.2 and 8.2).

X1.2.2.5 Radiographic source and film arrangement and radiation beam direction for each location.

NOTE X1.1—The RSS should designate the involved locations and



GENERAL INFORMATION

COMPANY PREPARING RSS

COMPANY PERFORMING RT

FOUNDRY CASTING IDENTIFICATION METHOD
STAMPED ☒ ETCHED ☐ AT RT LOCATION 9-10

SURFACE CONDITION WHEN RT'D
AS CAST ☐ ROUGH MACH'D ☒ FINISH MACH'D ☐

CASTING IDENTIFICATION

DRAWING NO. | REVISION | PIECE NO.

DESCRIPTION **BODY**

MATERIAL **NI-CU** | MATERIAL SPEC.

PATTERN NO. | HEAT NO.

RSS APPROVAL

SUPPLIER		CUSTOMER	
1.	DATE	1.	DATE
2.	DATE	2.	DATE

SAMPLE

RT PARAMETERS

VIEWS	1-2 thru 4-1	5-6 thru 7-8	9-10	11-12	13			
SOURCE TYPE	IRID 192	→	→	→	→			
FINISHED THICKNESS	13/16"	3/4"	5/8"–2-1/8	5/8"–2-3/8	3/4"–2-3/8			
THICKNESS WHEN RT'D	15/16"	7/8"	3/4"–2-5/16	3/4"–2-1/2	7/8"–2-1/2			
PENETRAMETER(S)	17	17	15 – 45	15 – 50	17 – 50			
SOURCE TO FILM DISTANCE	30"	→	→	→	→			
FILM TYPE	1	→	1 & 2	→	→			
FILM SIZE	5 X 7	→	8 X 10	→	→			
QUALITY LEVEL	2 - 2T	→	→	→	→			
ACCEPTANCE STANDARD	ASTM E-272	→	→	→	→			
SEVERITY LEVEL	2	→	→	→	→			

NOTES

REVISIONS

REV.	DESCRIPTION	APPROVAL SUPPLIER BY	SUPPLIER DATE	CUSTOMER BY	CUSTOMER DATE
A	ORIGINAL ISSUE	—	—	—	—

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FIG. X1.1 Sample Radiographic Standard Shooting Sketch (RSS)

stipulate that the technique for those locations is typical, for sections of the casting on which a continuing series of locations are to be radiographed with the same basic source and film arrangement for each location.

X1.2.3 Fig. X1.1 of this appendix provides a sample RSS that has been developed for a typical production application, and Figs. X1.2 and X1.3 provide sample RSS sketches that have been developed for a typical production application.

X1.2.4 The RSS may not provide what is considered to be the most effective means of technique control for all radiographic activities, but, in any event, some means of technique standardization should be employed. As a general rule, it is a beneficial practice for the supplier to solicit purchaser approval of the radiographic methodology prior to performing production radiography. This generally entails the demonstration of the adequacy of the methodology by submitting the proposed technique parameters and a corresponding set of pilot radiographs to the purchaser for review. Purchaser approval of the technique shall be addressed in the applicable job order or contract.

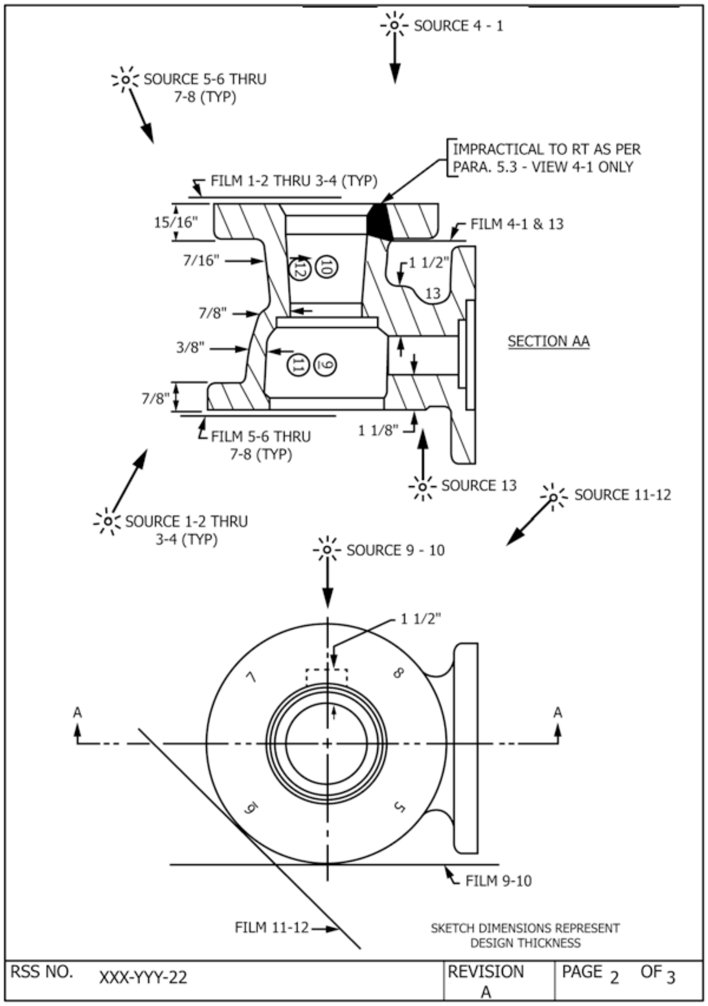


FIG. X1.2 Samples of Radiographic Standard Shooting Sketches (RSS) Views Illustrating Layout of Source and Film Placement

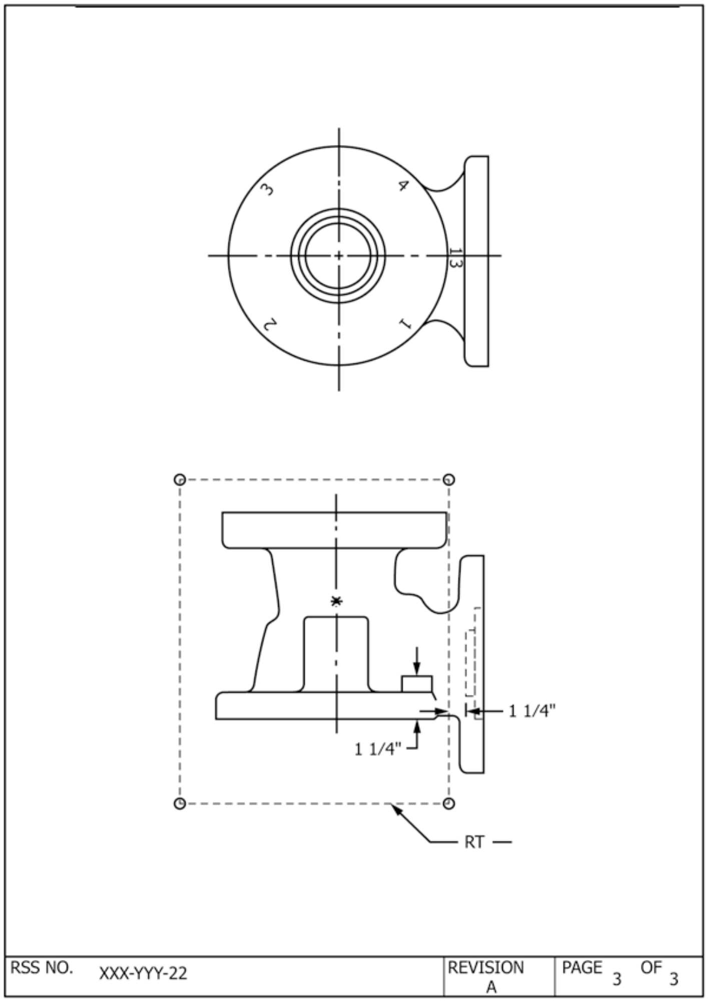
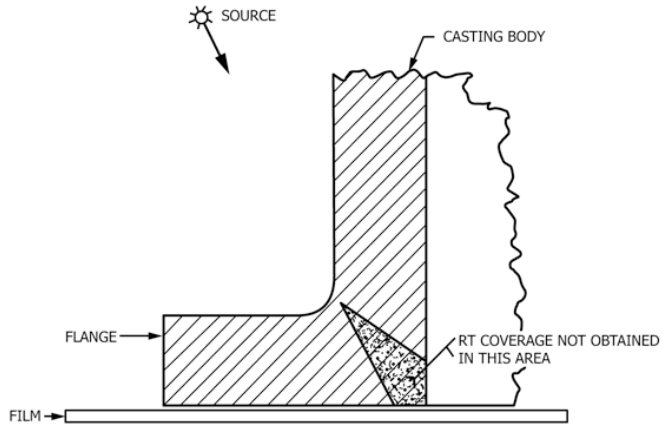


FIG. X1.3 Samples of Radiographic Standard Shooting Sketches (RSS) Views Illustrating Layout and Extent of Coverage

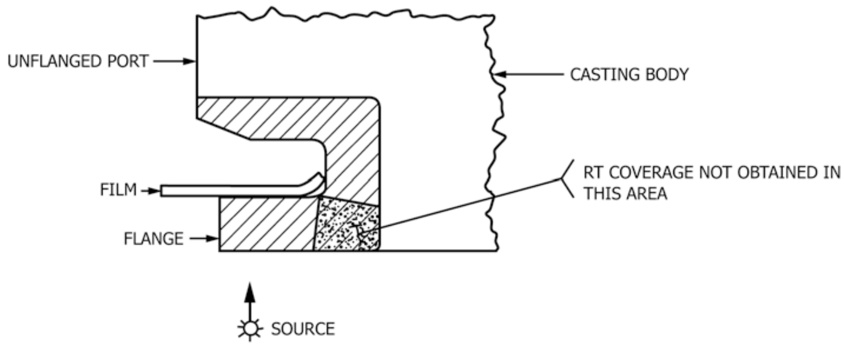
X2. PREFERRED SOURCE AND FILM ALIGNMENT FOR FLANGE RADIOGRAPHY AND EXAMPLES OF AREAS THAT ARE CONSIDERED IMPRACTICAL TO RADIOGRAPH

X2.1 *Preferred Source and Film Alignment for Flange Radiography*—The effective use of radiography for assessing material soundness in casting areas where a flange joins a body is somewhat limited by the source and film alignment that the geometric configuration of these areas require. The following figures (see Figs. X2.1-X2.3) describe source and film alignments that can be employed and discusses the limits and benefits of each.



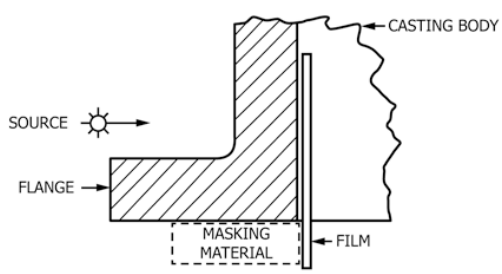
NOTE 1—For general application, this alignment provides the most effective compromise of quality radiography and maximum obtainable coverage.

FIG. X2.1 Preferred Source and Film Alignment



NOTE 1—This alignment provides a suitable alternative when other casting appendages (bosses, flanges, etc.) project into the radiation path as illustrated in Fig. X2.2 when this alignment is used, additional losses in coverage (as opposed to Fig. X2.1) should be expected and noted accordingly on the applicable RSS.

FIG. X2.2 Permissible Source and Film Alignment when Fig. X2.1 **Cannot Be Applied Due to Casting Geometry**



NOTE 1—This alignment is permissible if the radiation source energy and film multi-load capabilities are sufficient to afford compliance with the technique requirements stipulated herein. This alignment will generally require the use of filters or masking to reduce the influence of radiation that undercuts the thicker areas and reduces overall radiographic quality.

FIG. X2.3 Allowable Source Film Alignment as Governed by Source Energy and Multi-Film Load Acceptable Density Latitude

X3. EXAMPLES OF AREAS THAT ARE CONSIDERED TO BE IMPRACTICAL TO RADIOGRAPH

X3.1 Certain casting geometry configurations are inaccessible for conventional source and film arrangements that will provide meaningful radiographic results. These areas generally involve the juncture of two casting sections. The following illustrations (see Fig. X3.1 and Fig. X3.2) provide typical examples of such areas.

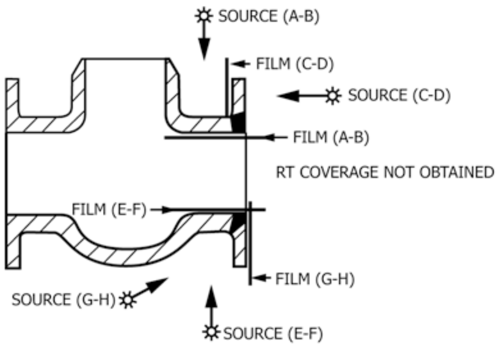


FIG. X3.1 Areas Involving Flanges

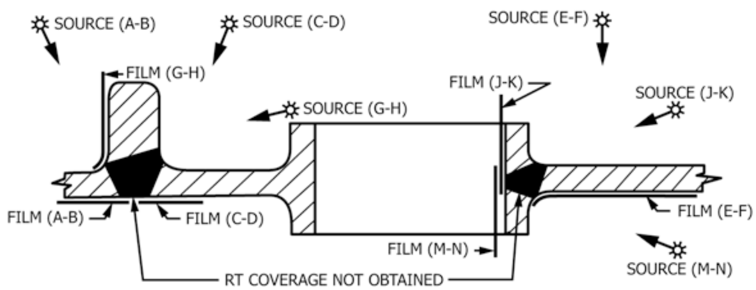


FIG. X3.2 Areas Involving Other Junctures

STANDARD TEST METHOD FOR DETERMINING THE SIZE OF IRIDIUM-192 INDUSTRIAL RADIOGRAPHIC SOURCES

SE-1114

(Identical with ASTM Specification E1114-09(R2014).)

Standard Test Method for Determining the Size of Iridium-192 Industrial Radiographic Sources

1. Scope

1.1 This test method covers the determination of the size of an Iridium-192 radiographic source. The determination is based upon measurement of the image of the Iridium metal source in a projection radiograph of the source assembly and comparison to the measurement of the image of a reference sample in the same radiograph.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E1316 Terminology for Nondestructive Examinations

E1815 Test Method for Classification of Film Systems for Industrial Radiography

E2445 Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems

E2597 Practice for Manufacturing Characterization of Digital Detector Arrays

2.2 *Other International Standards:*

EN 12679:2000 Industrial Radiography—Radiographic Method for the Determination of the Source Size for Radioisotopes

3. Terminology

3.1 For definitions of terms relating to this test method, refer to Terminology E1316.

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the size of the source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film or digital detector. This test method allows the user to determine the size of the source and to use this result to establish source to object and object to film or detector distances appropriate for maintaining the desired degree of geometric unsharpness.

NOTE 1—The European standard CEN EN 12579 describes a simplified procedure for measurement of source sizes of Ir-192, Co-60 and Se-75. The resulting source size of Ir-192 is comparable to the results obtained by this test method.

5. Apparatus

5.1 *Subject Iridium-192 Source,* the source size of which is to be determined. The appropriate apparatus and equipment for the safe storage, handling, and manipulation of the subject source, such as a radiographic exposure device (also referred to as a gamma ray projector or camera), remote control, source guide tube, and source stop are also required.

5.2 *Reference Sample (see* Figs. 1-3*)*—The reference sample shall be of material which is not radioactive. The recommended material is Iridium. However, substitutes such as platinum, tungsten or other material of similar radiopacity may be used. The sample should be of the same geometric shape as the subject source, should be approximately the same size as the subject source, and should be positioned on or within a shim or envelope to simulate the source capsule wall. The

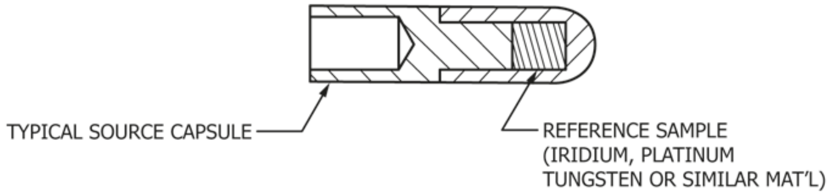


FIG. 1 Reference Sample in Standard Source Encapsulation

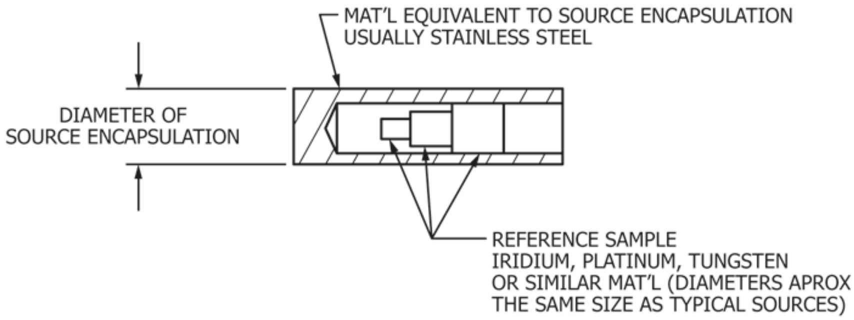


FIG. 2 Alternate Reference Sample Arrangement

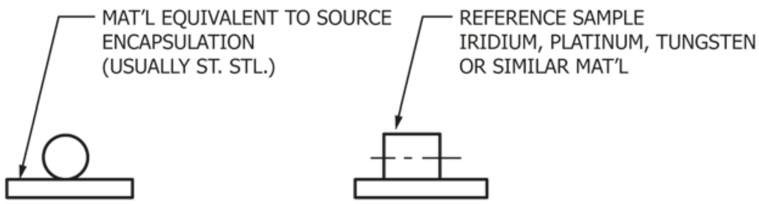


FIG. 3 Alternate Reference Sample Arrangement

resulting radiographic contrast, with reference to adjacent background density of the image of the reference sample, should be approximately the same as that of the subject source. The actual dimensions of the reference sample should be determined to the nearest 0.025 mm (0.001 in.).

5.3 *X-ray Generator,* capable of producing a radiation intensity (roentgen per hour at one metre) at least ten times greater than that produced by the subject source. Examples of typical X-ray generator output requirements that satisfy this criterion are presented in Table 1.

5.4 *Film systems*—Only film systems having cognizant engineering organization approval or meeting the system class requirements of Test Method E1815, for system classes I, II or Special, shall be used. Selection of film systems should be determined by such factors as the required radiographic quality level, equipment capability, materials and so forth. The film system selected shall be capable of demonstrating the required image quality. No intensifying screens shall be used. Radiographic films shall be processed in accordance with Guide E999.

TABLE 1 Examples of Typical X-ray Generator Output Requirements for Related Iridium^{192} Source Activities

Subject Iridium^{192} Source Radiation			Typical X-ray Generator Output Requirements	
Activity (Curie)	Output (R/h at 1 m)		Potential	Current
30	14.4		160 kV	5 mA
		or	200 kV	3 mA
100	48.0		160 kV	10 mA
		or	250 kV	4 mA
200	96.0		160 kV	20 mA
		or	250 kV	8 mA
		or	300 kV	6 mA

5.5 *Image Measurement Apparatus*—This apparatus is used to measure the size of the image of the spot. The apparatus shall be an optical comparator with built-in graticule with 0.1 mm divisions or 0.001 in. divisions and magnification of 5× to 10×.

5.6 *Digital Detectors*—Digital detectors, which are either imaging plates or digital detector arrays, may be used as film replacement. The digital detector shall possess a pixel pitch which is at least 40 times smaller than the nominal source size to measure and a basic spatial resolution smaller than 1⁄20 of the nominal source size. The basic spatial resolution shall be measured in accordance with the procedure of Practice E2597 for DDAs or Practice E2445 for the imaging plate scanner system or taken from manufacturer statements. In the area of free beam a detector SNR_D > 100 shall be achieved. The measurement procedure of the SNR shall be in accordance with the procedure of Practice E2597 for DDAs or Practice E2445 for the imaging plate scanner system.

5.7 *Evaluation of Digital Images*—Digital images shall be evaluated by an image processing software with contrast, brightness, profile and zoom function. The digital images shall be magnified at the monitor to a degree that allows the image viewing with at least one pixel of the image at one pixel of the monitor.

6. Procedure

6.1 Set up the exposure arrangement as shown in Figs. 4-7. Position the X-ray tube directly over the center of the film or digital detector. The film or detector plane must be normal to the central ray of the X-ray beam. The X-ray spot should be 0.90 m (36 in.) from the film or detector. Position the reference sample and apparatus used to locate the subject source (source stop) as close together as possible and directly over the center of the film or detector. The plane of the source stop and reference sample must be parallel to the film or detector and normal to the central ray of the X-ray beam. The source stop and reference sample should be 0.15 m (6 in.) from the film or detector. The source stop should be connected to the radiographic exposure device by the shortest source guide tube practicable in order to minimize fogging of the film or detector during source transit.

6.2 Place identification markers to be imaged on the film or detector to identify, as a minimum, the identification (serial number) of the subject source, the size of the reference sample, the identification of the organization performing the determination, and the date of the determination. Care should be taken to ensure that the images of the subject source and reference sample will not be superimposed on the image of the identification markers.

6.3 *Exposure*—Select the X-ray tube potential (kV), X-ray tube current (mA) and exposure time such that the density in the image of the envelope surrounding the reference sample does not exceed 3.0 and that the density difference between the image of the reference sample and the image of the envelope surrounding the reference sample is at least 0.10. In digital images the linear grey value difference between the image of the reference sample and the image of the envelope surrounding the reference sample shall be five times larger than the image noise σ(σ = standard deviation of the grey value fluctuations in an area of homogeneous exposure, measured in a window of at least 20 by 55 pixels) in a homogeneous neighbor area.

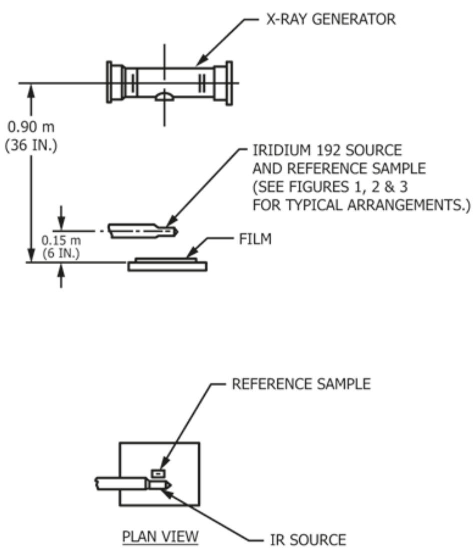


FIG. 4 Typical Exposure Arrangement

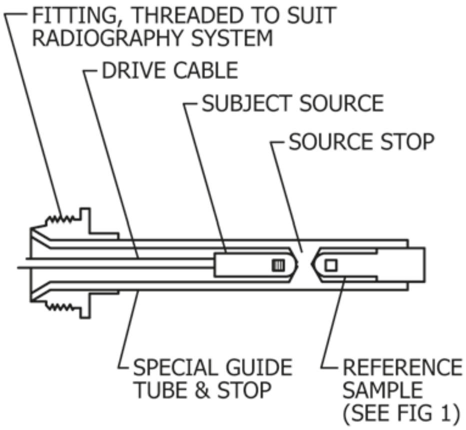


FIG. 5 Typical Arrangement Using a Specially Designed Guide Tube

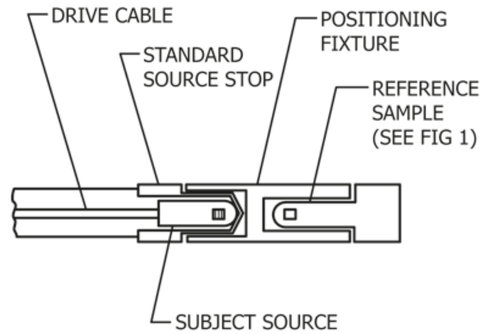


FIG. 6 Typical Arrangement Using a Standard Guide Tube and Special Positioning Fixture

NOTE 2—The actual parameters that will produce acceptable results may vary between X-ray units, and trial exposures may be necessary.

6.3.1 Energize the X-ray generator and, at the same time, manipulate the subject source into the exposure position in the source stop. It is important that this be performed as quickly as possible to minimize fogging of the film or detector.

6.3.2 At the conclusion of the exposure time, deenergize the X-ray generator and, at the same time, return the subject source to the proper shielded storage position.

6.3.3 Process the film or read out the digital detector array or scan the imaging plate.

7. Measurement of Source Dimensions

7.1 When viewing the film radiograpgh, view it with sufficient light intensity for adequate viewing. Using an optical comparator with built-in graticule as described in 5.5, measure the linear dimensions of the image of the spot size of the subject source and the reference sample. Take measurements

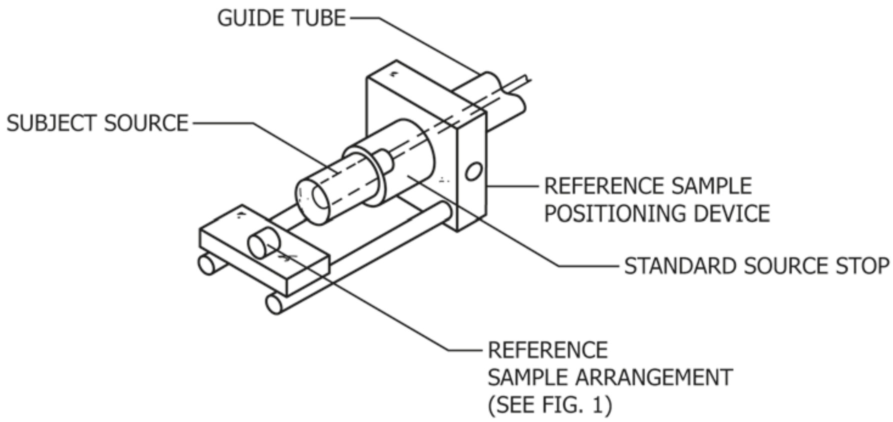


FIG. 7 Typical Arrangement Using Reference Sample Positioning Device

from the perceptible edges of the image. When performing the physical measurements with the optical comparator, the actual measured values shall be to the nearest graduation on the graticule scale being used.

7.2 When viewing the digital image, view it in a darkened room and use a bright monitor with at least 250 cd/m^2. Use the profile function of the image processing software for size measurement in digital images after proper brightness and contrast adjustment.

7.3 The source size for a given technique is the maximum projected dimension of the source in the plane perpendicular to a line drawn from the source to the object being radiographed. Therefore, sufficient measurements of the image of the Iridium must be made to determine the size of the source in any orientation. Sections 7.4 – 7.7 serve as examples.

7.4 *Uniform Right Circular Cylinder* (see Fig. 8)—Determine the source size of a uniform right circular cylindrical source by measuring the diameter, *d*, the height, *h*, and the diagonal, *m*, as illustrated in Fig. 8 and computing the actual dimensions as described in 8.1.

7.5 *Sphere* (see Fig. 9)—Determine the size of a spherical source by measuring the diameter, *d*, as illustrated in Fig. 9 and computing the actual dimension as described in 8.1.

7.6 *Nonuniform Stack of Right Circular Cylinders* (see Fig. 10)—Determine the size of a nonuniform stack of right circular cylindrical components of a source by measuring the intrinsic diameter, *d*, the height, *h*, and the effective maximum dimension, *m*, as illustrated in Fig. 10 and computing the actual dimensions as described in 8.1.

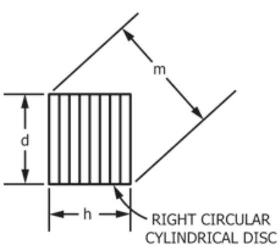


FIG. 8 Uniform Right Circular Cylinder

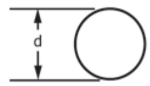


FIG. 9 Sphere

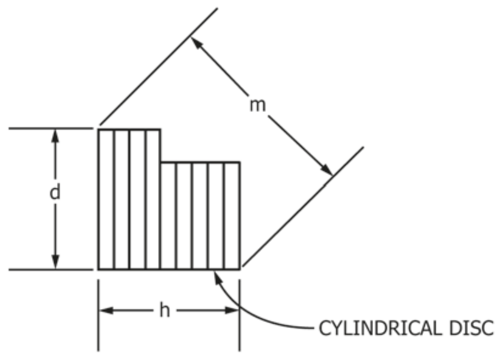


FIG. 10 Nonuniform Cylindrical Stack

7.7 *Separated Stack of Right Circular Cylinders* (see Fig. 11)—Determine the size of a separated stack of right circular cylindrical components of a source by measuring the intrinsic diameter, *d*, the effective height, *h*, and the effective maximum dimension, *m*, as illustrated in Fig. 11 and computing the actual dimensions as described in 8.1.

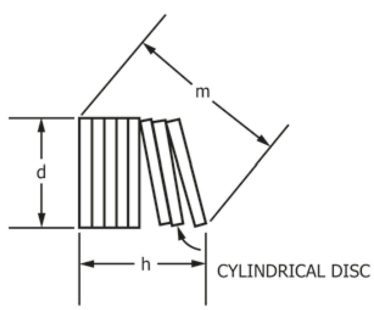


FIG. 11 Separated Cylindrical Stack

8. Calculation and Evaluation

8.1 Measure the linear dimension of interest in the subject source image and measure the same linear dimension in the reference sample image (that is, the diameter of each). The actual dimension of the subject source is computed from the following:

$$a = bc/d$$

where:

a = actual dimension of the subject source,
b = actual dimension of the reference sample,
c = measured dimension of the subject source image, and
d = measured dimension of the reference sample image.

9. Report

9.1 A report of the size of an Iridium-192 source should indicate the model number and serial number of the source, the name of the organization making the determination, the date the determination was made, a description of the shape of the source (or an appropriate sketch), and the calculated actual dimensions. The actual radiograph should accompany the report.

10. Precision and Bias

10.1 *Precision*—It is not possible to specify the precision of the procedure in this test method for measuring the size of Iridium-192 radiographic sources because round robin testing has not yet been accomplished.

10.2 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring the size of Iridium-192 radiographic sources because round robin testing has not yet been accomplished.

11. Keywords

11.1 cylinder(s); Iridium 192; radiographic source; reference sample; source size; sphere

STANDARD TEST METHOD FOR MEASUREMENT OF FOCAL SPOTS OF INDUSTRIAL X-RAY TUBES BY PINHOLE IMAGING

SE-1165

(Identical with ASTM Specification E1165-12.)

Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging

1. Scope

1.1 The image quality and the resolution of X-ray images highly depend on the characteristics of the focal spot. The imaging qualities of the focal spot are based on its two dimensional intensity distribution as seen from the detector plane.

1.2 This test method provides instructions for determining the effective size (dimensions) of standard and mini focal spots of industrial x-ray tubes. This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a "pinhole" technique.

1.3 This standard specifies a method for the measurement of focal spot dimensions from 50 µm up to several mm of X-ray sources up to 1000 kV tube voltage. Smaller focal spots should be measured using EN 12543-5 using the projection of an edge.

1.4 This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

1.5 Values stated in SI units are to be regarded as the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E1000 Guide for Radioscopy

E1255 Practice for Radioscopy

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2033 Practice for Computed Radiology (Photostimulable Luminescence Method)

E2698 Practice for Radiological Examination Using Digital Detector Arrays

2.2 *European Standards:*

EN 12543-2 Non-destructive testing—Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing—Part 2: Pinhole camera radiographic method

EN 12543-5 Non-destructive testing—Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing—Part 5: Measurement of the effective focal spot size of mini and micro focus X-ray tubes

2.3 *Papers:*

Klaus Bavendiek, Uwe Heike, Uwe Zscherpel, Uwe Ewert And Adrian Riedo, "New measurement methods of focal spot size and shape of X-ray tubes in digital radiological applications in comparison to current standards," WC-NDT 2012, Durban, South Africa

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *actual focal spot*—the X-ray producing area of the target as viewed from a position perpendicular to the target surface (see Fig. 1).

3.1.2 *effective focal spot*—the X-ray producing area of the target as viewed from a position perpendicular to the tube axis in the center of the X-ray beam (see Fig. 1).

3.1.3 *effective size of focal spot*—focal spot size measured in accordance with this standard.

4. Summary of Test Method

4.1 This method is based on a projection image of the focal spot using a pinhole camera. This image shows the intensity distribution of the focal spot. From this image the effective size of the focal spot is computed. A double integration of a profile

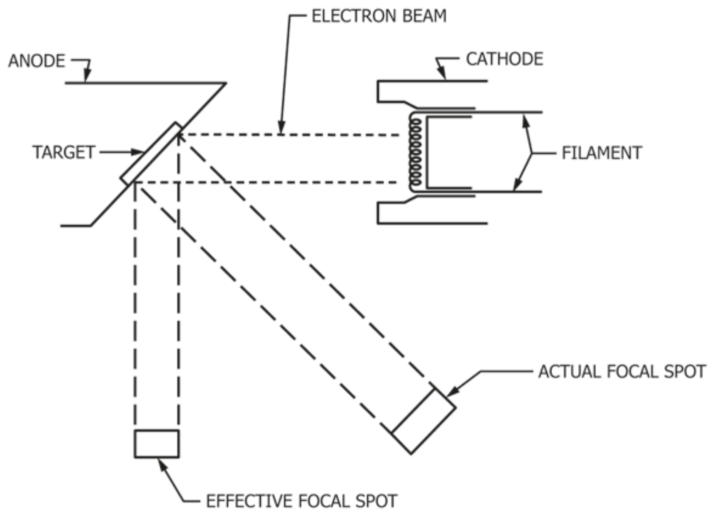


FIG. 1 Actual/Effective Focal Spot

across the pinhole image transforms the pinhole image into an edge profile. The X- and Y-dimension of the edge unsharpness is used for calculation of the size of the focal spot. This method provides similar results as the method described in EN 12543-5 using an edge target instead of a pinhole camera. The measured effective spot sizes correspond to the geometrical image unsharpness values at given magnifications as measured with the ASTM E2002 duplex wire gauge in practical images using equation:

$$u_G = \Phi(v - 1) \quad (1)$$

with geometrical unsharpness u_G, focal spot size Φ and magnification v (see ASTM E1000 for details of this equation). For a full description see Reference 2.3.

4.2 Additionally, a simplified test method is described in the annex A for users of X-ray tubes who may not intend to use a pinhole camera. This alternative method is based on the edge method in accordance with EN 12543-5 using a plate hole IQI as described in ASTM E1025 or E1742 instead of a pinhole camera.

5. Significance and Use

5.1 One of the factors affecting the quality of radiologic images is the geometric unsharpness. The degree of geometric unsharpness is dependent on the focal spot size of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the detector (imaging plate, Digital Detector Array (DDA) or film). This test method allows the user to determine the effective focal size of the X-ray source. This result may then be used to establish source to object and object to detector distances appropriate for maintaining the desired degree of geometric unsharpness and/or maximum magnification for a given radiographic imaging application. Some ASTM standards require this value for calculation of a required magnification, for example, E1255, E2033, and E2698.

6. Apparatus

6.1 *Pinhole Diaphragm*—The pinhole diaphragm shall conform to the design and material requirements of Table 1 and Fig. 3.

6.2 *Camera*—The pinhole camera assembly consists of the pinhole diaphragm, the shielding material to which it is affixed, and any mechanism that is used to hold the shield/diaphragm in position (jigs, fixtures, brackets, and the like).

6.3 *Alignment and Position of the Pinhole Camera*—The angle between the beam direction and the pinhole axis (see Fig. 4) shall be smaller than ±1.5°. When deviating from Fig. 4, the direction of the beam shall be indicated. The incident face of the pinhole diaphragm shall be placed at a distance *m* from the focal spot so that the variation of the magnification over the extension of the actual focal spot does not exceed ±5 % in the beam direction. In no case shall this distance be less than 100 mm.

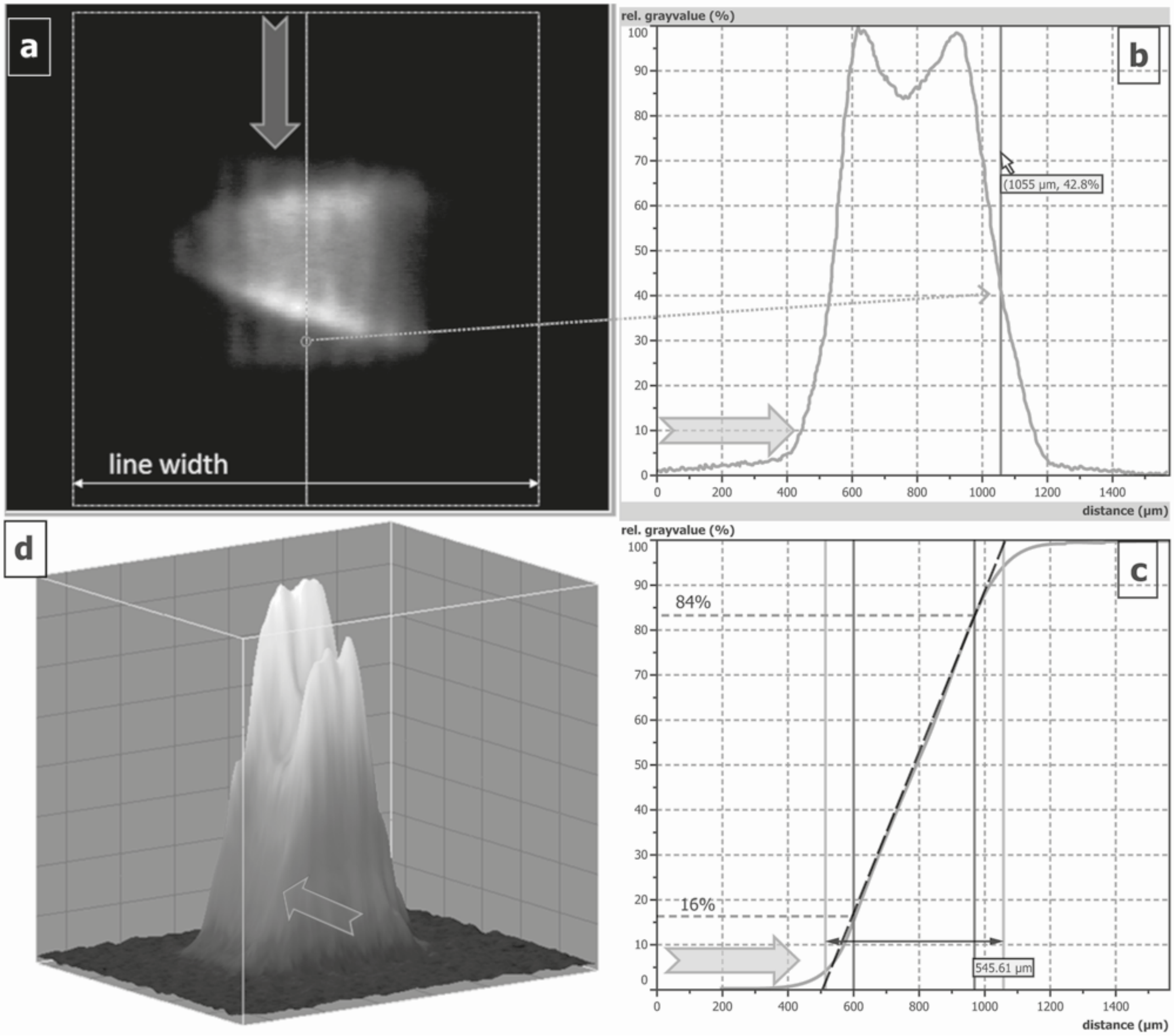
6.4 *Position of the Radiographic Image Detector*—The radiographic image detector (film, imaging plate or DDA) shall be placed normal to the beam direction at a distance *n* from the incident face of the pinhole diaphragm determined from the applicable magnification according to Fig. 5 and Table 2.

TABLE 1 Pinhole Diaphragm Design Requirements (Dimension)[A]

NOTE 1—The pinhole diaphragm shall be made from one of the following materials: *(1)* An alloy of 90 % gold and 10 % platinum, *(2)* Tungsten, *(3)* Tungsten carbide, *(4)* Tungsten alloy, *(5)* Platinum and 10 % Iridium Alloy, or *(6)* Tantalum.

Focal Spot Size mm	Diameter P μm	Height H μm
0.05 to 0.3	10 ± 5	50 ± 5
0.3 to 0.8	30 ± 5	75 ± 10
>0.8	100 ± 5	500 ± 10

[A] See Fig. 3.



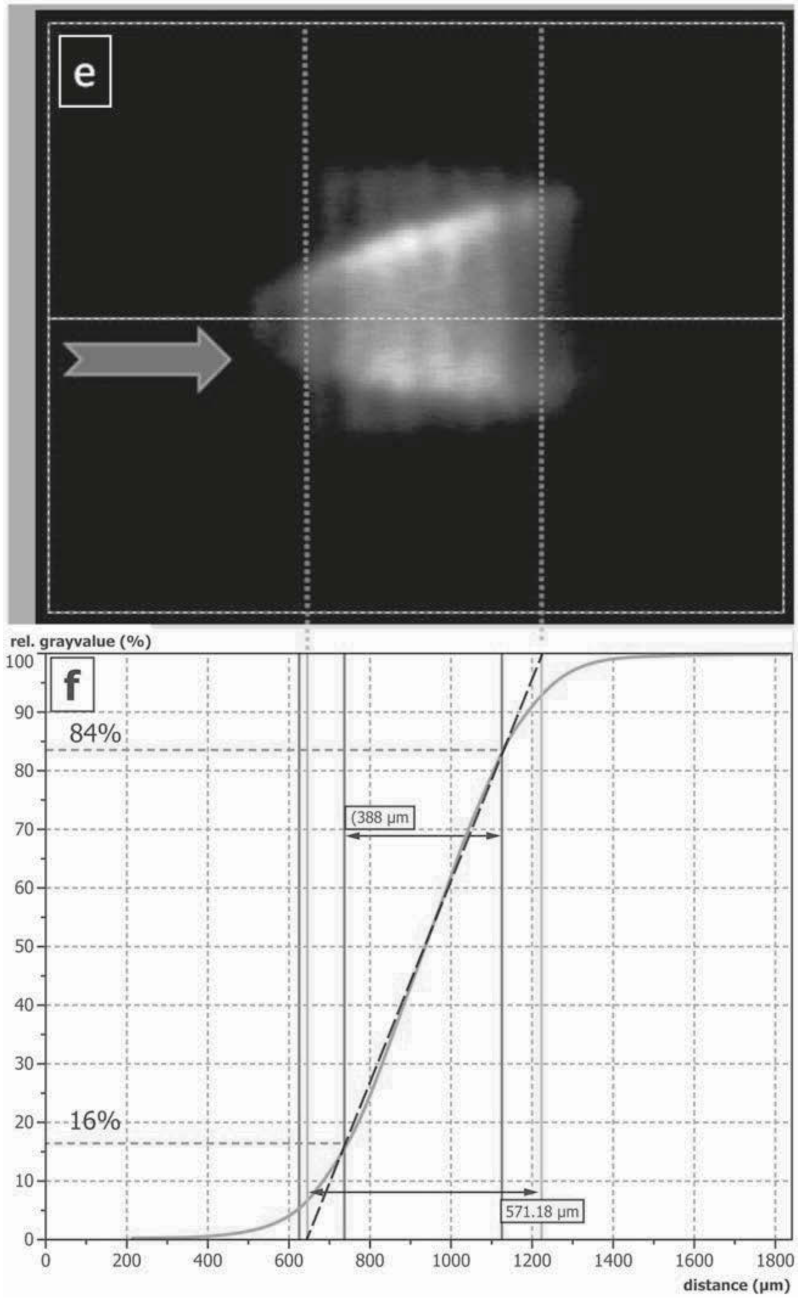
(a) Image of a double line Focal Spot with the Location and Size of the Line Profile in Length Direction.
(b) Line Profile in the direction of the large arrow averaged over the dotted rectangle of Fig. 2a.
(c) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black), corresponding to the Klasens method of E1000.
(d) Pseudo 3D Image of the Focal Spot; the large arrow points in the direction of the Line Profile.
(e) Image of a double line Focal Spot with the Location and Size of the Line Profile in Width Direction.
(f) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black) for the Width Direction.

FIG. 2 Example for the Measurement of Effective Focal Spot Length and Width with the Integrated Line Profile (ILP) Method

6.5 *Radiographic Image Detector*—Analogue or digital radiographic image detectors may be used, provided sensitivity, dynamic range and detector unsharpness allow capturing of the full spatial size of the focal spot image without detector saturation. The maximum allowed detector unsharpness is given by the geometrical unsharpness u_G of the pinhole and the pinhole diameter P. It is calculated according to (see Fig. 5).

$$u_G = P(1 + n/m) \quad (2)$$

6.5.1 The detector unsharpness shall be determined with the duplex wire IQI in accordance with ASTM E2002. The minimum projected length and width of the focal spot image should be covered always by at least 20 detector pixels in digital images. The signal-to-noise ratio of the focal spot image (ratio of the maximum intensity value inside the focal spot and the standard deviation of the background signal outside) should be at least 50. The maximum intensity inside the focal spot



(e) Image of a double line Focal Spot with the Location and Size of the Line Profile in Width Direction.

(f) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black) for the Width Direction.

FIG. 2 Example for the Measurement of Effective Focal Spot Length and Width with the Integrated Line Profile (ILP) Method *(continued)*

should be above 30 %, but lower than 90 % of the maximum linear detector output value. The grey value resolution of the detector shall be in minimum 12 Bit.

6.5.2 Imaging plate systems (Computed Radiography, CR) or digital detector arrays (DDA) may be used as digital image detectors following practices E2033 or E2698. The pixel values shall be linear to the dose.

6.5.3 If radiographic film is used as image detector, it shall meet the requirements of E1815 film system class I or Special and shall be packed in low absorption cassettes using no screens. The film shall be exposed to a maximum optical density between 1.5 and 2.5. The film shall be digitized with a maximum pixel of 50 µm or a smaller size, which fulfills the requirements of the above unsharpness conditions and be

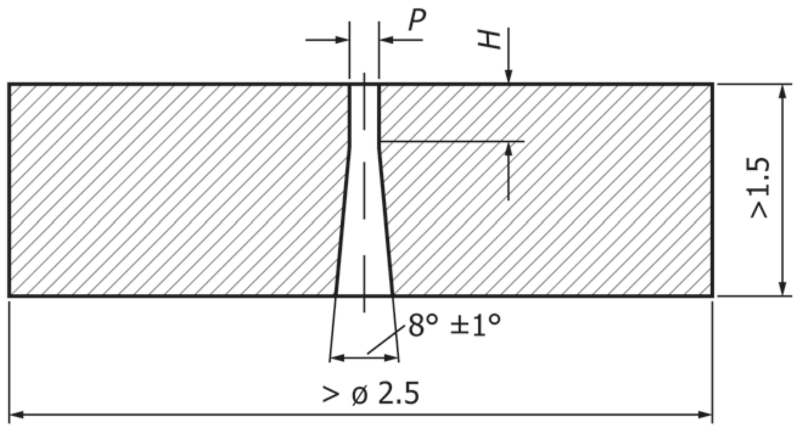


FIG. 3 Essential Dimensions of the Pinhole Diaphragm

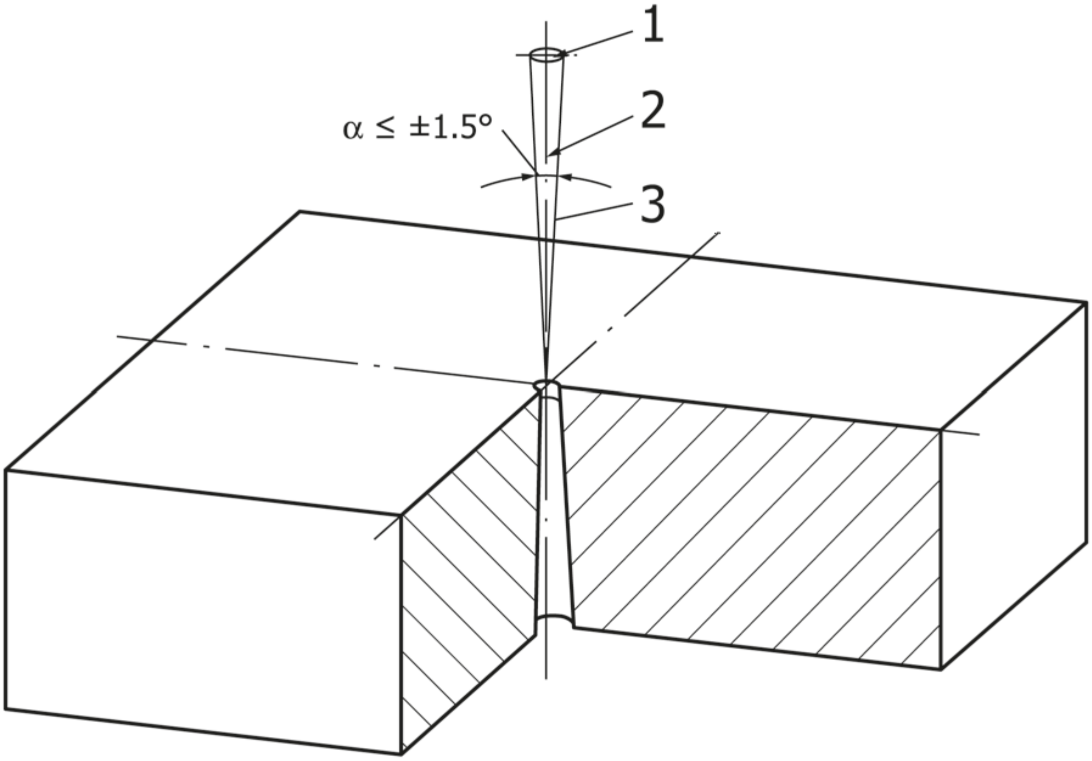


FIG. 4 Alignment of the Pinhole Diaphragm

evaluated according to Eq 2. If the user has no digital equipment the film may be evaluated visually; the procedure is shown in 7.9. The film shall be processed in accordance with Guide E999.

6.6 *Image Processing Equipment*—This apparatus is used to capture the images and to measure the intensity profile of the focal spot in the projected image. The image shall be a positive image (more dose shows higher grey values) and linear proportional to the dose. The equipment shall be able:

(1) to calibrate the pixel size with a precision of 2 µm or 1 % of the pixel size,

(2) to draw line profiles and average the line profiles over a preset area,

(3) to integrate line profiles by the length of the line profile,

(4) to subtract the background using a linear interpolation (straight line) of both ends of the line profile using at least the average of 10 % of the line profile as support on both ends, and

(5) to calculate the X- and Y-dimension of the focal spot in the image with two threshold values of 16 % and 84 % of the integrated line profile and extrapolate the width to 100 % (see Fig. 2).

NOTE 1—The software for this calculation can be downloaded from

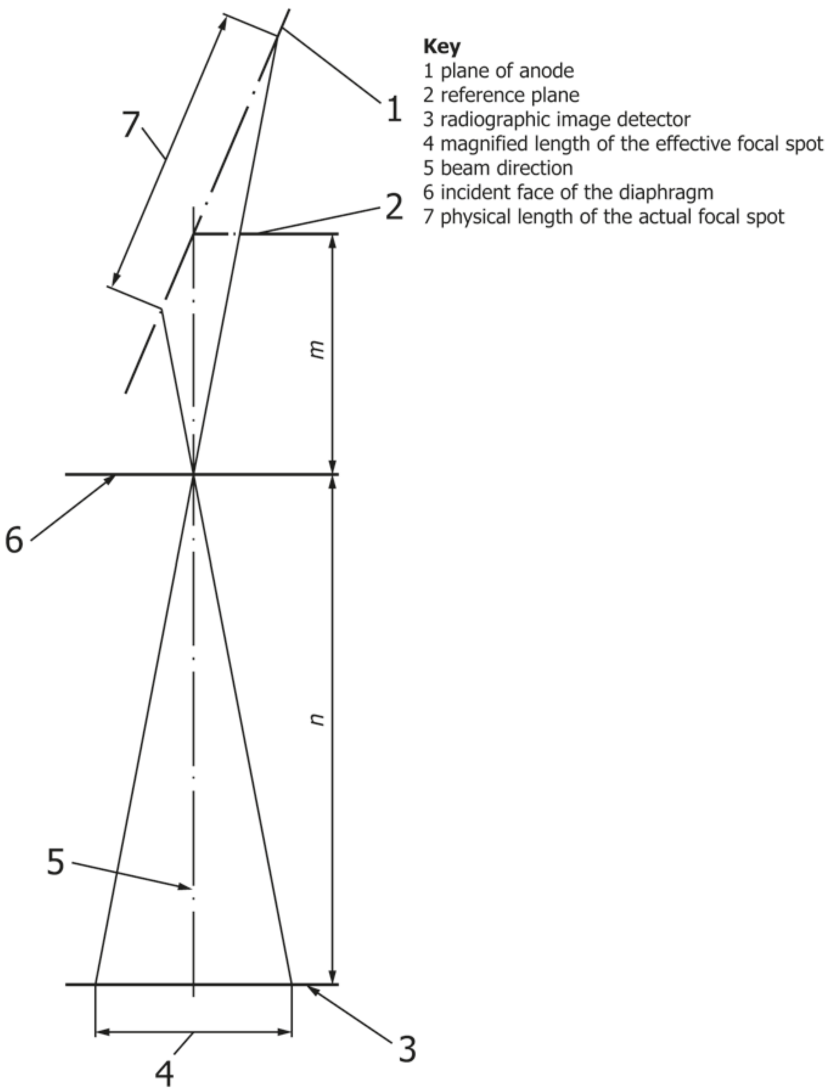


FIG. 5 Beam Direction Dimensions and Planes

TABLE 2 Magnification for Focal Spot Pinhole Images

Anticipated Focal Spot Size d [mm]	Minimum Magnification n/m	Distance between Focal Spot and Pinhole [m][A]	Distance between Pinhole and Detector [n][A]
0.05 to 2.0	3 : 1	0.25	0.75
>2.0	1 : 1	0.5	0.5

[A] When using a technique that entails the use of enlargement factors and a 1 m focal spot to detector distance (FDD = *m*+*n*) is not possible (see 7.1), the distance between the focal spot and the pinhole (*m*) shall be adjusted to suit the actual focal spot to detector distance (FDD) used (for example, if a 600 mm FDD is used, *m* shall be 150 mm for 3:1 enlargement, 300 mm for 1:1 enlargement, and the like).

http://dir.bam.de/ic (or http://www.kb.bam.de/~alex/ic/index.html).

6.6.1 When using CR technology or digitized film where outliner pixel may occur, a median 3×3 filter shall be available.

7. Procedure

7.1 If possible, use a standard 1 m (40 in.) focal spot to detector distance (FDD = *m*+*n*) for all exposures. If the machine geometry or accessibility limitations will not permit the use of a 1 m FDD, use the maximum attainable FDD (in these instances adjust the relative distances between focal spot, pinhole, and detector accordingly to suit the image enlargement factors specified in Table 2). For small focal spots FDD may be larger than 1 m (40 in.) to meet the requirements in 6.5 and 7.5. The distance between the focal spot and the pinhole is based on the anticipated size of the focal spot being measured and the desired degree of image enlargement (see Fig. 5). The specified focal spot to pinhole distance (*m*) for the different focal spot size ranges is provided in Table 2. Position the pinhole such that it is within ±1.5° of the central axis of the X-ray beam.

NOTE 2—The accuracy of the pinhole system is highly dependent upon the relative distances between (and alignment of) the focal spot, the pinhole, and the detector. Accordingly, a specially designed apparatus may be necessary in order to assure compliance with the above requirements. Fig. 6 provides an example of a special collimator that can be used to ensure conformance even with ±1° alignment tolerance.

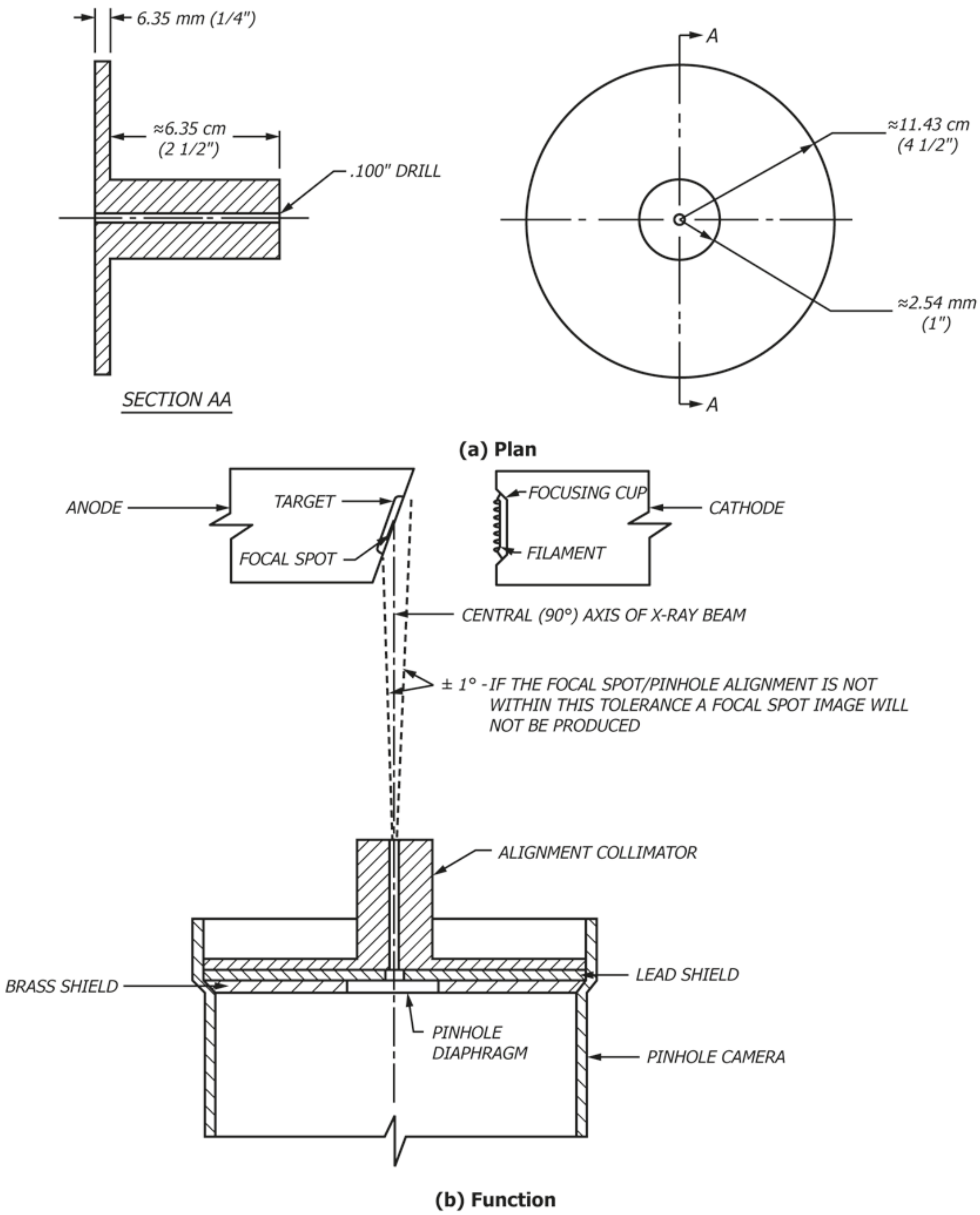


FIG. 6 Exposure Set-Up Schematic

7.2 Position the detector as illustrated in Fig. 7. When using film as detector, the exposure identification appearing on the film (by radiographic imaging) should be X-ray machine identity (make and serial number), organization making the radiograph, energy (kV), tube current (mA) and date of exposure. When the film is digitized or a digital detector is used, this information shall be stored within the image or file name.

7.3 Adjust the kilovoltage settings on the X-ray machine to 75 % of the nominal tube voltage, but not more than 200 kV for evaluation with film. For evaluation with a DDA or CR the maximum voltage is limited by the condition that the background intensity is lower than the half of the maximum intensity inside the focal spot. The X-ray tube current shall be the maximum applicable tube current at the selected voltage. For measurements with more than 200 kV an optional copper prefilter may be used to prevent saturation of the imaging device.

7.4 Expose the detector as given in 6.5. When using CR or film, the maximum pixel value or density shall be controlled by exposure time only. With a DDA the internal detector settings (frame time and/or sensitivity) shall be selected that the conditions of 6.5 are met.

NOTE 3—The required SNR can be achieved with a DDA system by

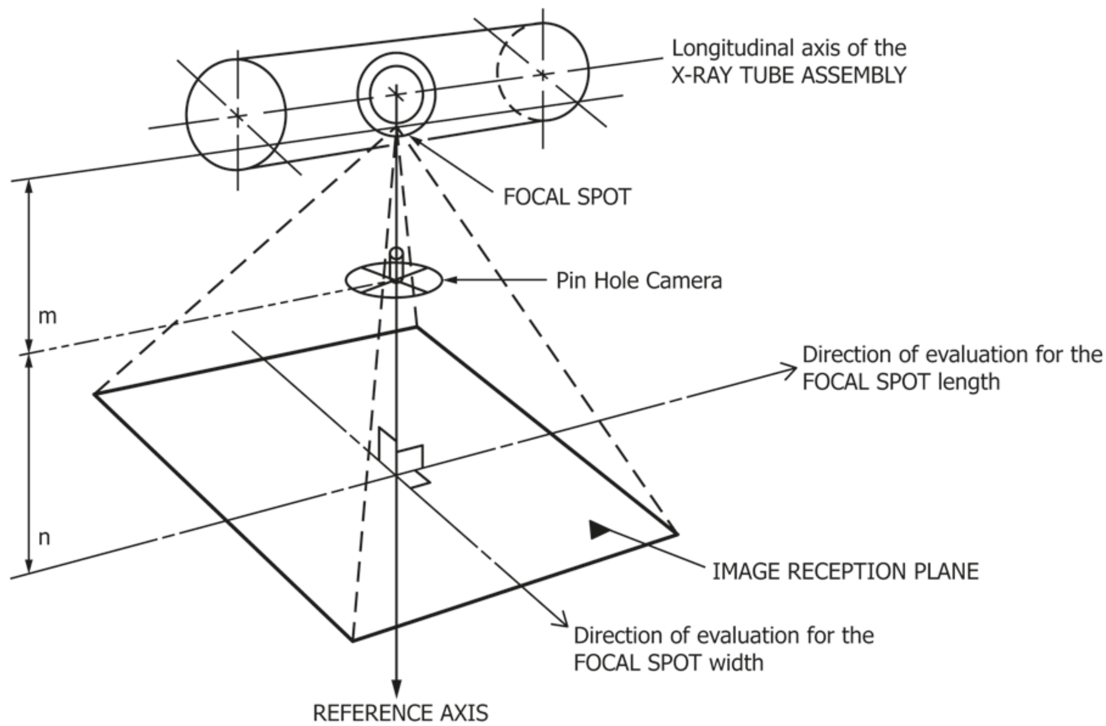


FIG. 7 Exposure Set-Up Schematic and Focal Spot WIDTH (X) and LENGTH (Y) Specification

integration of frames with identical exposures in the computer. For detail refer to ASTM E2736.

7.5 Before evaluation the image shall be inspected for spikes or outliners (CR and digitized film only). These artifacts shall be removed using a median 3×3 filter. In this case the size of the focal spot in the image shall be >40 pixels in both directions.

7.6 The images shall be stored with the nomenclature of 7.2 in 16 Bit lossless Image Format, for example, TIFF or DICONDE.

7.7 The pixel size in the image shall be calibrated by a known object size in the image like a "ruler" or by measured geometry with the precision of 1 % of the pixel size.

7.8 *Focal Spot Measurement using Integrated Line Profiles (ILP):*

7.8.1 A line profile shall be drawn in length or width direction through the maximum intensity of the focal spot. The line profile shall be accumulated perpendicular to the profile direction over about 3 times the anticipated focal spot size (see Fig. 2). The line profile should have a length of at least 3 times the anticipated focal spot size. The background shall be subtracted using a linear interpolation (straight line) of both ends of the line profile, using at least the average of 10 % of the line profile as support on both ends. Now the line profile shall be integrated (accumulated). Then the points on the resulting curve at which the curve has 16 % and 84 % of its max value shall be determined (see Klasens method of E1000, and Fig. 16 in E1000). The distance between these points is extrapolated to the theoretical 0 % and 100 % values of the total focal spot intensity by a multiplication with 1.47. The result is the size of the focal spot in the direction of the integrated line profile.

NOTE 4—By using the values of 16 % and 84 % instead of 0 % and 100 % the determined size is 32 % too small. The factor 1.47 = 100/(100–32) extrapolates this to 100 %.

7.8.2 This measurement shall be done in two directions (see Fig. 2 and Fig. 7):

7.8.2.1 *Direction X*—Vertical to the electron beam direction (width).

7.8.2.2 *Direction Y*—Parallel to the electron beam direction (length).

7.9 *Focal Spot Evaluation for Users Without Digital Equipment:*

7.9.1 If radiographic film is used as an image detector and it can't be digitized, it shall be evaluated visually using an illuminator with a uniform luminance of 2000 to 3000 cd/m^2. The visual evaluation shall be carried out using an ×5 or ×10 magnifying glass, with a built-in reticle, with divisions of 0.1 mm. The resulting focal spot shall be defined by the visible extent of the blackened area, divided by the selected magnification factor. An example is shown in Fig. 8.

8. Classification and Report

8.1 The focal spot shall be classified according to its measured size. The preferred values of focal spot sizes and dedicated classes are consistent with ASTM E2002. The values for width and length shall be taken separately and the maximum determines the focal spot class as shown in Table 3. An example of a dual focal spot X-ray tube is given in Table 4.

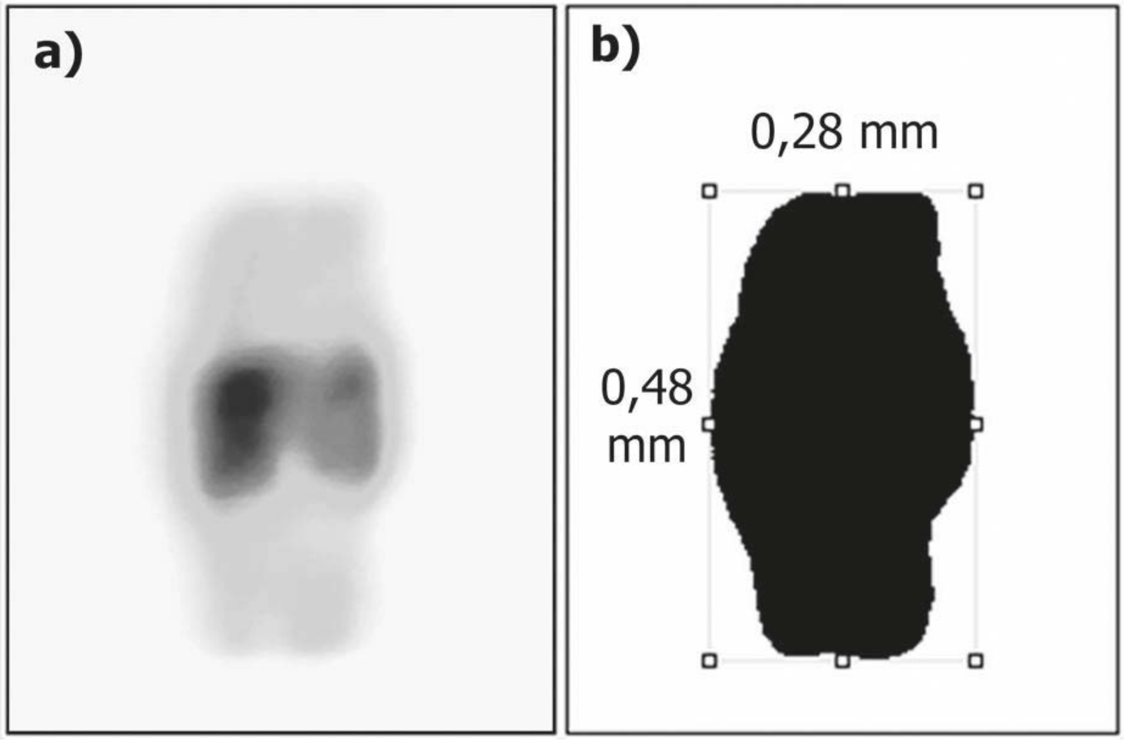


FIG. 8 Example of Visual Film Evaluation with Magnifying Glass

TABLE 3 Preferred Values of Focal Spot Sizes and Dedicated Classes

FS 0				FS	>	4	mm
FS 1	4	mm	≥	FS	>	3.2	mm
FS 2	3.2	mm	≥	FS	>	2.5	mm
FS 3	2.5	mm	≥	FS	>	2	mm
FS 4	2	mm	≥	FS	>	1.6	mm
FS 5	1.6	mm	≥	FS	>	1.27	mm
FS 6	1.27	mm	≥	FS	>	1	mm
FS 7	1	mm	≥	FS	>	0.8	mm
FS 8	0.8	mm	≥	FS	>	0.63	mm
FS 9	0.63	mm	≥	FS	>	0.5	mm
FS 10	0.5	mm	≥	FS	>	0.4	mm
FS 11	0.4	mm	≥	FS	>	0.32	mm
FS 12	0.32	mm	≥	FS	>	0.25	mm
FS 13	0.25	mm	≥	FS	>	0.2	mm
FS 14	0.2	mm	≥	FS	>	0.16	mm
FS 15	0.16	mm	≥	FS	>	0.127	mm
FS 16	0.127	mm	≥	FS	>	0.1	mm
FS 17	0.1	mm	≥	FS	>	0.08	mm
FS 18	0.08	mm	≥	FS	>	0.063	mm
FS 19	0.063	mm	≥	FS	>	0.05	mm
FS 20	0.05	mm	≥	FS	>	0.04	mm

8.2 A report documenting the focal spot size determination should include the image name (see 7.6), machine model number and serial number, the X-ray tube serial number, the focal spot(s) that was measured (some X-ray tubes have dual focal spots), the set-up and exposure parameters (for example, kilovoltage, milliamps, enlargement factor, and the like), date, name of organization, and estimated beam time hours (if available).

8.3 A print of the focal spot image may be added to the report for information purposes only.

TABLE 4 Example of Classification Result

Company XXR 225-22							
	Measured Width (X)		Measured Length (Y)	Reported Width (X)		Reported Length (Y)	Focal Spot Class
Large Focus (3000W)	2.32 mm	×	1.63 mm	2.5 mm	×	2.0 mm	FS3
Small Focus (640W)	0.461 mm	×	0.452 mm	0.5 mm	×	0.5 mm	FS10

9. Precision and Bias

9.1 *Statement of Precision:*

9.1.1 There is no standard x-ray tube focal spot that can be measured and compared to the measurement results; therefore, repeatability precision is defined as the comparison of repeated measurements of a given focal spot with different hardware and within three different laborites. A round robin test report in accordance with ASTM E691 was done with a 160 kV /HP11 tube, using CR technology with 5 different CR plates. The parameter were: 120 kV, 5.3 mA, 20 s exposure time, magnification 4.25, pinhole diameter 30 µm, scanner pixel size 25 µm (5.9 µm effective pixel size), SNR = 78.

9.1.2 The mean value of the length of the focal spot is 0.5553 mm and the width 0.5510 mm. The standard deviation is 0.004937 mm for the length and 0.00446 mm for the width (0.89 % and 0.81 %). In the ASTM E691 evaluation the external and internal consistency values are within the critical interval of 0.5 % significance level for focal spot length and width.

9.2 *Statement on Bias:*

9.2.1 There is no standard x-ray tube focal spot size that can be measured and compared to the measurement results; therefore, a bias can not be measured. Due to the measurement procedure there is no identified cause for a bias.

10. Keywords

10.1 focal spot; pinhole camera; pinhole imaging; X-ray; X-ray tube

ANNEX

(Mandatory Information)

A1. ALTERNATE FOCAL SPOT MEASUREMENT METHOD FOR END USERS

A1.1 Scope

A1.1.1 User of X-Ray tubes may use alternatively an ASTM plate hole IQI for measurement of the focal spot size. This method should provide equivalent values as the method described above but with less accuracy.

A1.2 Background Information for Calculation of Unsharpness Due to Focal Spot Size

A1.2.1 ASTM E2698 uses a formula to calculate the total unsharpness in the image. As shown in ASTM E1000 two reasons can be separated: Unsharpness from the detector and unsharpness from the focal spot size and geometrical magnification.

$$U_{Im} = \frac{1}{v} \cdot \sqrt[3]{U_g^3 + (1.6 \cdot SR_b)^3} \quad (A1.1)$$

$$U_g = (v - 1) \cdot \Phi \quad (A1.2)$$

A1.2.1.1 The part from the focal spot is given in ASTM E1000 as shown in Eq A1.2 and can be extracted from Eq A1.1:

$$U_g = v \cdot \sqrt[3]{U_{Im}^3 - \left(\frac{1.6}{v} \cdot SR_b\right)^3} \quad (A1.3)$$

A1.2.1.2 Bringing Eq A1.2 into Eq A1.3 the focal spot size can be written as:

$$\Phi = FS = \frac{v}{v-1} \sqrt[3]{U_{Im}^3 - \left(\frac{1.6}{v} \cdot SR_b\right)^3} \quad (A1.4)$$

A1.2.1.3 Practical tests have shown and in Wagner[4] is calculated that the square root fits better for this measurement procedure. With that the unsharpness from focal spot size in the image shall be calculated by:

$$\Phi = FS = \frac{v}{v-1} \sqrt[2]{U_{Im}^2 - \left(\frac{2.0}{v} \cdot SR_b\right)^2} \quad (A1.5)$$

A1.2.1.4 This method uses the edges of a large hole in a thin plate for measurement of the focal spot size. The method is similar to the EN 12543-5. Here, instead of wires or spheres of high absorbing material, hole type IQIs are used.

A1.3 Apparatus

A1.3.1 *ASTM E1025 or E1742 IQI*—The type of IQI should fit to the focal spot size (see Table A1 and Fig. A1.1). The material should be stainless steel or copper. The IQI shall be placed on a shim block of stainless steel, brass or copper and the material thickness of the shim block shall be two time the thickness of the IQI in use.

A1.3.2 *Radiographic Image Detector*—A radiographic image detector which is used in the x-ray system shall also be used for image capture.

[4] Robert F. Wagner et al, Toward a unified view of radiological imaging systems; Part I (1974) and Part II (1977).

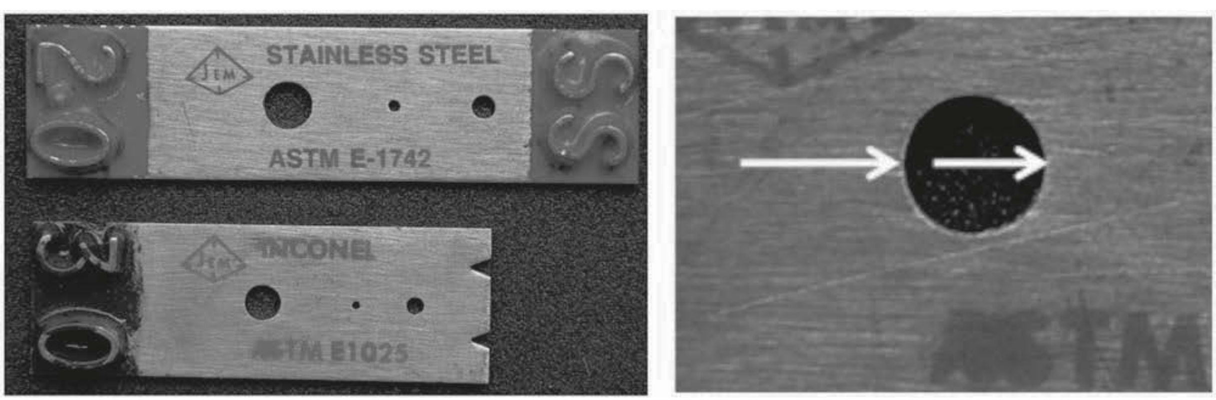


FIG. A1.1 ASTM IQIs for Measurement of Spot Size by Edge Evaluation

A1.3.3 *Image Processing Equipment*—This apparatus is used to capture the images. The image shall be linear proportional to the dose. The equipment shall be able:

(1) to calibrate the pixel size with a precision of 1 µm or 1/100 of the anticipated focal spot size—whatever is larger,

(2) to draw averaged line profiles with a width which is adjustable, and

(3) to measure distances in the line profile with the precision of 1/50 of the anticipated focal spot size (see Fig. A1.2).

(4) (optional) a software routine shall be available which is doing the calibration of measurement of the edge unsharpness automatically using the hole size, the pixel size and SR_b as reference for the calibration (see Fig. A1.3).

A1.4 Procedure

A1.4.1 The evaluation shall be done in the X-ray system where the X-ray tube is integrated.

A1.4.2 The IQI should be placed on a Brass, Copper or Inconel shim block with two times the thickness (t) of the thickness of the IQI (T):

$$t\ 2\cdot T \tag{A1.6}$$

A1.4.2.1 The IQI hole diameter shall fit to the anticipated focal spot size (afs). The diameter of the hole shall be smaller than fifteen times the anticipated focal spot size and larger than two times the focal spot size.

A1.4.2.2 The energy shall be 75 % (±5 %) of maximum energy of the tube but not more than the maximum voltage used in all applications. The tube current shall be the maximum which is possible at that voltage. The exposure time (CR) or the internal integration time and sensitivity (DDA and Radioscopy) shall be adjusted that the signal in the hole of the IQI is in the range of 30 % to 90 % of the maximum signal possible. The area of the IQI beside the hole shall have a signal of in minimum 10 % of the maximum signal possible. If these conditions cannot be achieved with the setup, a thinner or thicker IQI shall be used together with an adapted shim block. The 2T hole or the 4T hole should be used. A minimum magnification of 2 shall be used.

A1.4.2.3 Furthermore, the minimum magnification v_{min} shall be selected in relation to the effective pixel size SR_b determined with the duplex wire IQI in accordance with ASTM E2002 and afs:

$$v_{min} = 5\cdot SR_b/afs \tag{A1.7}$$

A1.4.2.4 The angle of penetration of the IQI shall be 90° (±1.5°).

A1.4.2.5 It shall be assured that the size inside the hole profile is in minimum four times larger than the size of the unsharpness of the edge profile. Additionally the diameter of the hole in the image shall be more than 100 pixels.

A1.4.3 An image shall be captured. The SNR shall be larger than 100 in the image on the IQI beside the 4T hole.

A1.4.3.1 If the SNR is larger than 300 a digital magnification of factor two with a bilinear (or higher degree) interpolation between the pixel may be used.

A1.4.4 The pixel size in the image shall be calibrated by a known object size in the image for example, the IQI dimension of the plate or of the 4T hole. The precision of calibration shall be 1/100 of the hole diameter.

A1.5 Evaluation

A1.5.1 *Manual Evaluation Using a Line Profile:*

A1.5.1.1 A line profile shall be drawn in horizontal direction and it shall be averaged over in minimum 5 pixel or the width of 1/20 of the hole diameter.

A1.5.1.2 A marker shall be set at 50 % (±2 %) of the signal inside the hole. A second marker shall be placed at a position of 34 % more signal compared to the first marker with same tolerance (84 % ± 2 %). The distance between both markers shall be noted (in real units or in pixels). A third marker shall be set at the opposite side of the IQI hole at 50 % (±2 %) and a fourth at a position of 34 % more signal compared to the third marker with same tolerance (84 % ± 2 %). The distance between both markers shall be noted as before; see Fig. A1.2 for an example. The values of the first distance difference and the second distance difference shall be summed.

A1.5.1.3 The evaluation for the vertical direction shall be done in the same manner.

A1.5.1.4 The values are measured from 50 % to 84 %; to extrapolate to 100 % both values shall be multiplied by the factor of 1.4 (Note A1.1).

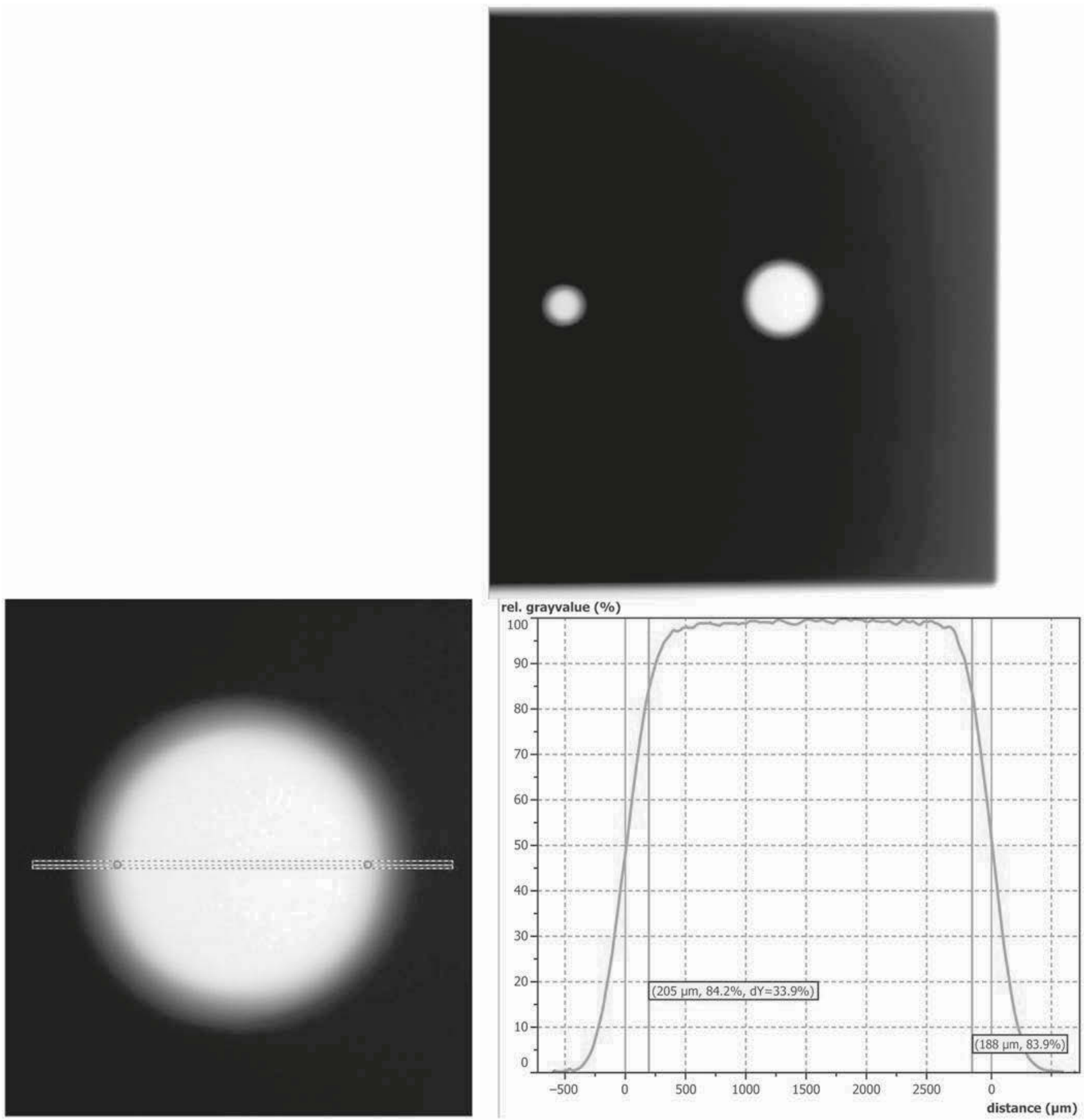
NOTE A1.1—To compensate the bias of about 5 % higher values the extrapolation factor is reduced from 1.47 to 1.4. The bias is caused by the fact that the edges are not in the center of the beam and therefore the X-rays do not penetrate it at a 90 degree angle.

A1.5.1.5 The resulting unsharpness still contains the unsharpness due to the detector. Therefore the results have to be corrected using Eq A1.5 in A1.2 to calculate the effective focal spot size.

A1.5.1.6 The corrected values of the effective focal spot size shall be assigned to the X or Y direction of the X-ray tube (depending on the orientation of the tube in the X-ray system; see Fig. 7 for the assignment).

A1.5.2 *Automatic Evaluation Using a Software Function:*

A1.5.2.1 A Region of Interest (ROI) shall be drawn around the hole with about double the diameter of the hole. The calibration of the pixel size shall be done by entering the hole size in real units, the pixel size and the detector resolution SR_b. The software shall calculate the calibration value by using the 50 % signal level threshold in both horizontal and vertical direction. Then the software shall evaluate the unsharpness on the four edges in vertical and horizontal direction using 50 % and 84 % thresholds. The values of the two edges for vertical unsharpness shall be summed and the same shall be done for the horizontal direction. The results shall be extrapolated to



NOTE 1—Correction with detector unsharpness and the extrapolation factor of 1.4 shall be applied for final calculation of the effective focal spot size.

NOTE 2—The effective focal spot size of the example shown in Fig. A1.2 is 550 µm in horizontal direction.

NOTE 3—The measurement is performed in analogy to the method of measurement of micro focus spot sizes of EN 12543-5.

FIG. A1.2 Measurement of the Focal Spot Size from the Horizontal Edge Profile with Thresholds of 50 % to 84 % on Both Sides of the Line Profile

100 % with the extrapolation factor of 1.4 (Note A1.1) and then corrected for the detector unsharpness using the correction Eq A1.5 from A1.2 within the software.

A1.5.2.2 The results shall be recorded; it may also be displayed in the image (see Fig. A1.3) or written in a result file.

A1.5.2.3 The resulting values shall be assigned to the X or Y direction of the x-ray tube (depending of the orientation of the tube in the x-ray system; see Fig. 7 for the assignment).

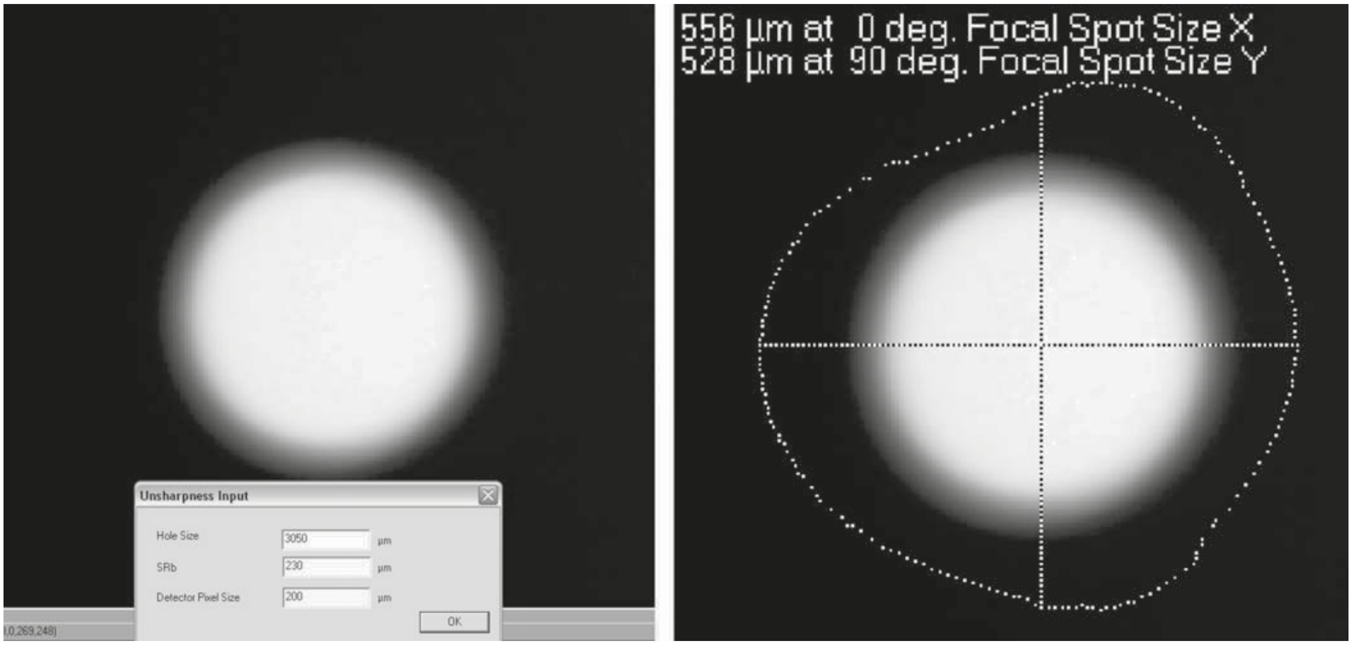


FIG. A1.3 Measurement of the Spot Size of the Four Edges with Threshold from 50 % to 84 % and Extrapolation with Factor 1.4 with Automatic Calculation of the Effective Focal Spot Size in X and Y Direction

A1.6 Report

A1.6.1 If one value is needed as effective focal spot size only, the maximum of the horizontal or vertical value shall be taken as the result of the test.

A1.7 Precision and Bias

A1.7.1 *Statement of Precision:*

A1.7.1.1 A test report in accordance with ASTM E691 was repeated with the tube of the reliability test of 9.1 using different positions of the IQI. The automatic evaluation with the software function was used. The parameter were 120 kV, 5.3 mA, Magnification 5.0, IQI hole size 3.05 mm (2T hole), pixel size 200 µm, SR_b = 230 µm, SNR = 420.

A1.7.1.2 The mean value of the length of the focal spot due to this method is 0.5406 mm and the width 0.5591 mm. The standard deviation is 0.017036 mm for the length and 0.008012 mm for the width (3.15 % and 1.43 %). In the ASTM E691 evaluation the external and internal consistency values are within the critical interval of 0.5 % significance level for focal spot length and width.

A1.7.1.3 Using the manual evaluation with the line profile the precision also depends on the exact position of the four markers in vertical and horizontal direction.

A1.7.2 *Statement on Bias:*

A1.7.2.1 As reference for the focal spot size the value of the ILP method was taken (see 9.1). The deviation of the user method to the reference values were –2.64 % for the length and 1.47 % for the width.

A1.7.2.2 Bias of the user method is produced by edge penetration of the IQI which may lead to larger values and the position of the IQI in length direction due to the steep angle of the target (see Fig. 1).

STANDARD PRACTICE FOR RADIOSCOPY

SE-1255

(Identical with ASTM Specification E1255-09.)

Standard Practice for Radioscopy

1. Scope

1.1 This practice provides application details for radioscopic examination using penetrating radiation. This includes dynamic radioscopy and for the purposes of this practice, radioscopy where there is no motion of the object during exposure (referred to as static radioscopic imaging) both using an analog component such as an electro-optic device or analog camera. Since the techniques involved and the applications for radioscopic examination are diverse, this practice is not intended to be limiting or restrictive, but rather to address the general applications of the technology and thereby facilitate its use. Refer to Guides E94 and E1000, Terminology E1316, Practice E747, Practice E1025, Test Method E2597, and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96 for a list of documents that provide additional information and guidance.

1.2 The general principles discussed in this practice apply broadly to penetrating radiation radioscopic systems. However, this document is written specifically for use with X-ray and gamma-ray systems. Other radioscopic systems, such as those employing neutrons, will involve equipment and application details unique to such systems.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see Section 8 and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*

E94 Guide for Radiographic Examination

E543 Specification for Agencies Performing Nondestructive Testing

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E1000 Guide for Radioscopy

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1316 Terminology for Nondestructive Examinations

E1411 Practice for Qualification of Radioscopic Systems

E1742 Practice for Radiographic Examination

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2597 Practice for Manufacturing Characterization of Digital Detector Arrays

2.2 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Federal Standards:*

21 CFR 1020.40 Safety Requirements of Cabinet X-Ray Systems

29 CFR 1910.96 Ionizing Radiation

2.4 *National Council on Radiation Protection and Measurement (NCRP) Standard:*

NCRP 49 Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up to 10 MeV

2.5 *AIA Standard:*

NAS-410 NAS Certification and Qualification of Nondestructive Test Personnel

3. Summary of Practice

3.1 Visual evaluation as well as computer-aided automated radioscopic examination systems are used in a wide variety of penetrating radiation examination applications. A simple visual evaluation radioscopic examination system might consist of a radiation source, a fluorescent screen viewed with an analog camera, suitably enclosed in a radiation protective enclosure and a video display. At the other extreme, a complex automated radioscopic examination system might consist of an X-ray source, a robotic examination part manipulator, a radiation protective enclosure, an electronic image detection system with a camera, a frame grabber, a digital image processor, an image display, and a digital image archiving system. All system components are supervised by the host computer, which incorporates the software necessary to not only operate the system components, but to make accept/reject decisions as well. Systems having a wide range of capabilities between these extremes can be assembled using available components. Guide E1000 lists many different system configurations.

3.2 This practice provides details for applying radioscopic examination with camera techniques; however, supplemental requirements are necessary to address areas that are application and performance specific. Annex A1 provides the detailed supplemental requirements for government contracts.

4. Significance and Use

4.1 As with conventional radiography, radioscopic examination is broadly applicable to any material or examination object through which a beam of penetrating radiation may be passed and detected including metals, plastics, ceramics, composites, and other nonmetallic materials. In addition to the benefits normally associated with radiography, radioscopic examination may be either a dynamic, filmless technique allowing the examination part to be manipulated and imaging parameters optimized while the object is undergoing examination, or a static, filmless technique wherein the examination part is stationary with respect to the X-ray beam. The differentiation to systems with digital detector arrays (DDAs) is the use of an analog component such as an electro-optic device or an analog camera. Recent technology advances in the area of projection imaging, camera techniques, and digital image processing provide acceptable sensitivity for a wide range of applications. If normal video rates are not adequate to detect features of interest then averaging techniques with no movement of the test object shall be used.

5. Equipment and Procedure

5.1 *System Configuration*—Many different radioscopic examination systems configurations are possible, and it is important to understand the advantages and limitations of each. It is important that the optimum radioscopic examination system be selected for each examination requirement through a careful analysis of the benefits and limitations of the available system components and the chosen system configuration. The provider as well as the user of the radioscopic examination services should be fully aware of the capabilities and limitations of the radioscopic examination system that is proposed for examination of the object. The provider and the user of radioscopic examination services shall agree upon the system configuration to be used for each radioscopic examination application under consideration, and how its performance is to be evaluated.

5.1.1 The minimum radioscopic examination system configuration will include an appropriate source of penetrating radiation, a means for positioning the examination object within the radiation beam, in the case of dynamic radioscopy, and a detection system. The detection system may be as simple as a camera-viewed fluorescent screen with suitable radiation shielding for personnel protection that meets applicable radiation safety codes.

5.1.2 A more complex system might include the following components:

5.1.2.1 An Image Intensifier to intensify the photon detection from the fluorescent screen,

5.1.2.2 A micro- or mini-focus X-ray tube can be used with high magnification to facilitate higher-resolution projection imaging,

5.1.2.3 A multiple axis examination part manipulation system to provide dynamic, full volumetric examination part manipulation under operator manual control or automated program control, for dynamic radioscopy,

5.1.2.4 An electronic imaging system to display a bright, two-dimensional gray-scale image of the examination part at the operator's control console,

5.1.2.5 A digital image processing system to perform image enhancement and image evaluation functions,

5.1.2.6 An archival quality image recording or storage system, and

5.1.2.7 A radiation protective enclosure with appropriate safety interlocks and a radiation warning system.

5.1.3 Whether a simple or a complex system is used, the system components and configuration utilized to achieve the prescribed examination results must be carefully selected.

5.2 *Practice:*

5.2.1 The purchaser and supplier for radioscopic examination services shall mutually agree upon a written procedure and also consider the following general requirements.

5.2.1.1 *Equipment Qualifications*—A listing of the system features that must be qualified to ensure that the system is capable of performing the desired radioscopic examination task. System features are described in Guide E1000.

5.2.1.2 *Examination Object Scan Plan for Dynamic Radioscopy*—A listing of object orientations, ranges of motions, and manipulation speeds through which the object must be manipulated to ensure satisfactory examination.

5.2.1.3 *Radioscopic Parameters*—A listing of all the radiation source-related variables that can affect the examination outcome for the selected system configuration such as: source energy, intensity, focal spot size, filter in the X-ray beam, collimators, range of source to object distances, range of object to image plane distances, and source to image plane distances.

5.2.1.4 *Image Processing Parameters*—A listing of all the image processing variables necessary to enhance flaw detectability in the object and to achieve the required sensitivity level. These would include, but are not limited to, techniques such as noise reduction, contrast enhancement, and spatial filtering. Great care should be exercised in the selection of directional image processing parameters such as spatial filtering, which may emphasize features in certain orientations and suppress them in others. The listing should indicate the means for qualifying image processing parameters.

5.2.1.5 *Image Display Parameters*—A listing of the techniques and the intervals at which they are to be applied for standardizing the image display as to brightness, contrast, focus, and linearity.

5.2.1.6 *Accept-Reject Criteria*—A listing of the expected kinds of object imperfections and the rejection level for each.

5.2.1.7 *Performance Evaluation*—A listing of the qualification tests and the intervals at which they are to be applied to ensure that the radioscopic examination system is suitable for its intended purpose.

5.2.1.8 *Image Archiving Requirements*—A listing of the requirements, if any, for preserving a historical record of the examination results. The listing may include examination images along with written or electronically recorded alphanumeric or audio narrative information, or both, sufficient to allow subsequent reevaluation or repetition of the radioscopic examination.

5.2.1.9 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, or similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.2.1.10 *Agency Evaluation*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Practice E543. The applicable revision of Practice E543 shall be specified in the contractual agreement.

6. Radioscopic Examination System Performance Considerations and Measurement

6.1 *Factors Affecting System Performance*—Total radioscopic examination system performance is determined by the combined performance of the system components that includes the radiation source, manipulation system (for dynamic radioscopy), detection system, information processing system, image display, automatic evaluation system, and examination record archiving system.

6.1.1 *Radiation Sources*—While the radioscopic examination systems may utilize either radioisotope or X-ray sources, X-radiation is used for most radioscopic examination applications. This is due to the energy spectrum of the X-radiation that contains a blend of contrast enhancing longer wavelengths, as well as the more penetrating, shorter wavelengths. X-radiation is adjustable in energy and intensity to meet the radioscopic examination test requirements, and has the added safety feature of discontinued radiation production when switched off. A radioisotope source has the advantages of small physical size, portability, simplicity, and uniformity of output.

6.1.1.1 X-ray machines produce a more intense X-ray beam emanating from a smaller focal spot than do radioisotope sources. X-ray focal spot sizes range from a few millimetres down to a few micrometres. Reducing the source size reduces geometric unsharpness, thereby enhancing detail sensitivity. X-ray sources may offer multiple or variable focal spot sizes. Smaller focal spots produce higher resolution when using geometrical magnification and provide reduced X-ray beam intensity, while larger focal spots provide higher X-ray intensity and produce lower resolution. Microfocus X-ray tubes are available with focal spots that may be adjusted to as small as a few micrometres in diameter, while still producing an X-ray beam of sufficient intensity so as to be useful for the radioscopic examination of finely detailed objects.

6.1.1.2 Conventional focal spots of 1.0 mm and larger are useful at low geometric magnification values close to 1×. Fractional focal spots ranging from 0.4 mm up to 1.0 mm are useful at geometric magnifications of up to approximately 2×. Minifocus spots in the range from 0.1 mm up to 0.4 mm are useful at geometric magnifications up to about 6×. Greater magnifications suggest the use of a microfocus spot size of less than 0.1 mm in order to minimize the effects of geometric unsharpness. Microfocus X-ray tubes are capable of focal spot sizes of less than 1 micrometre (10^{-6} metre) and are useful for geometric magnifications of more than 100×.

6.1.2 *Manipulation System for Dynamic Radioscopy*—The examination part manipulation system has the function of holding the examination object and providing the necessary degrees of freedom, ranges of motion, and speeds of travel to position the object areas of interest in the radiation beam in such a way so as to maximize the radioscopic examination system's response. In some applications it may be desirable to manipulate the radiation source and detection system instead of, or in addition to, the object. The manipulation system must be capable of smooth well-controlled motion, especially so for high-magnification microfocus techniques, to take full advantage of the dynamic aspects of the radioscopic examination.

6.1.3 *Detection System*—The detection system is a key element. It has the function of converting the radiation input signal containing part information, into a corresponding electronic output signal while preserving the maximum amount of object information. The detector may be a two-dimensional area detector providing an area field of view.

6.1.3.1 A simple detection system may consist of a fluorescent screen viewed directly by an analog camera. Advantages include a selectable resolution and low component costs. The disadvantages include noisy imagery due to inefficient light capture from the fluorescent screen and pin cushion distortion.

6.1.3.2 Most radioscopic systems use image intensifiers that increase the capture efficiency from a fluorescent screen, intensify and reduce the image to an output phosphor that is then captured by a standard analog or digital TV/CCD camera, or equivalent. The image intensifier enables increased frame rates, or higher examination throughputs in relation to the use of a fluorescent screen alone. This enables the use of a standard low cost camera resulting in much higher SNR than if the image intensifier were not used. Disadvantages of the image intensifier include image blooming, pin cushion distortion and a limited spatial resolution of about 100 to 400 µm.

6.1.3.3 Cameras in combination with image intensifiers may use analog or digital readout circuitry. Analog cameras may produce video signals and may be used with TV displays; digital cameras need computing devices for displaying the images. Digital cameras may be selected out of a wide range of options in spatial resolution, image size, sensitivity and frame rate.

6.1.4 *Information Processing System:*

6.1.4.1 The function of the information processing system is to take the output of the detection system and present a useful image for display and operator interpretation, or for automatic evaluation. The information processing system may take many different forms, and may process analog or digital information, or a combination of the two.

6.1.4.2 The information processing system includes all of the electronics and interfaces after the detection system to and including the image display and automatic evaluation system. Information system components include such devices as frame grabbers, image processors, and in general any device that processes radioscopic examination information after the detection system.

6.1.4.3 The digital image processing system warrants special attention, since it is the means by which radioscopic examination information may be enhanced. Great care must be exercised in determining which image processing techniques are most beneficial for the particular application. Directional spatial filtering operations, for example, must be given special attention as certain feature orientations are emphasized while others are suppressed. While many digital image processing operations occur sufficiently fast to follow time-dependent radioscopic system variables, others do not. Some image processing operations require significant image acquisition and processing time, so as to limit the dynamic response of the radioscopic examination, in dynamic radioscopic systems.

6.1.5 *Automatic Evaluation System*—Some radioscopic examination applications can be fully automated including the accept/reject decision through computer techniques. The automatic evaluation system's response to various examination object conditions must be carefully determined under actual operating conditions. The potential for rejecting good objects and accepting defective objects must be considered. Automatic evaluation system performance criteria should be mutually determined by the provider and user of radioscopic examination services.

6.1.6 *Image Display:*

6.1.6.1 The function of the image display is to convey radioscopic information about the examination object to the system operator. For visual evaluation systems, the displayed image is used as the basis for accepting or rejecting the object, subject to the operator's interpretation of the radioscopic image. The image display performance, size, and placement are important radioscopic system considerations.

6.1.6.2 When employing a television image presentation with row interlacing from an analog camera, vertical and horizontal resolution are often not the same. Therefore, the effect of raster orientation upon the radioscopic examination system's ability to detect fine detail, regardless of orientation, must be taken into account.

6.1.7 *Radioscopic Examination Record Archiving System*—Many radioscopic examination applications require an archival quality examination record of the radioscopic examination. The archiving system may take many forms, a few of which are listed in 6.1.7-6.1.7.7. Each archiving system has its own peculiarities as to image quality, archival storage properties, equipment, and media cost. The examination record archiving system should be chosen on the basis of these and other pertinent parameters, as agreed upon by the provider and user of radioscopic examination services. The reproduction quality of the archival method should be sufficient to demonstrate the same image quality as was used to qualify the radioscopic examination system. To reduce storage capacity image compression may be used. Lossless compression provides no degradation or loss in quality; care should be taken when using lossy compression like JPEG or MPEG that the resulting quality is equivalent to the original image. Care shall be taken about the lifetime of the image storage media.

6.1.7.1 Video hard copy device used to create an image from the video signal,

6.1.7.2 Laser print hard copy device used to create a film image.

6.1.7.3 Analog video tape recorder used to record the video signal on magnetic tape; characterized by long recording time at video frame rates; useful for capturing part motion,

6.1.7.4 Digital recording on magnetic tape used to store the image of the object digitally; characterized by limited storage capacity at video frame rates, when using no image compression,

6.1.7.5 Digital recording on optical disk used to store the image of the object digitally; consideration should be given to the type of optical storage because there are fundamentally two different types: write once read many times (WORM) where common formats are CD ROM or DVD ROM, where the radiological data cannot be erased or altered after the disk is created, and rewritable disks, where radiological data can be erased, altered, or signed with R/W symbol.

6.1.7.6 Digital recording on magnetic hard disks may record several hours or even days on one hard drive. Care should be taken about the limited reliability of hard drives and about the fact that radiological data can be erased or altered easily.

6.1.7.7 Digital records can be stored in a digital network or on a multi-disk system when a backup-system is available. Care should be taken about the fact that radiological data can be erased or altered easily.

6.1.8 *Examination Record Data*—The examination record should contain sufficient information to allow the radioscopic examination to be reevaluated or duplicated. Examination record data should be recorded contemporaneously with the radioscopic examination image, and may be in writing or a voice narrative, providing the following minimum data:

6.1.8.1 Radioscopic examination system designation, examination date, operator identification, operating turn or shift, and other pertinent examination and customer data,

6.1.8.2 Specific part data as to part number, batch, serial number, etc. (as applicable),

6.1.8.3 Examination part orientation and examination site information by manipulation system coordinate data or by reference to unique part features within the field of view, and

6.1.8.4 System performance monitoring by recording the results of the prescribed radioscopic examination system performance monitoring tests, as set forth in Section 5, at the beginning and end of a series of radioscopic examinations, not to exceed the interval set forth in 6.2.2 for system performance monitoring.

6.2 *Performance Measurement*—Radioscopic examination system performance parameters shall be determined initially and monitored regularly to ensure consistent results. The best measure of total radioscopic examination system performance can be made with the system in operation, utilizing an object similar to the part under actual operating conditions. Tests with natural discontinuities are not sufficient as the only quality control measurement for the comparison of the actual system performance with its qualified state. The performance of the radioscopic system should be tested to its ability to image and recognize the typical and the critical discontinuities of a certain component. In addition to standardized IQIs, samples with the smallest or most difficult to detect natural discontinuities or simulated imperfections, for example, drilled holes, may be used as reference objects for a routine quality control of the overall system performance. In place of real samples, objects or reference blocks containing realistic or manufactured discontinuities can be used to check quality performance. Performance measurement methods shall be a matter of agreement between the provider and user of radioscopic examination services.

6.2.1 *System Performance Quality Parameter*—The quality of a radioscopic image is essentially determined by unsharpness, contrast, noise and linearity. The X-ray settings shall be the same as in production (energy, intensity, filter, FDD, FOD).

6.2.2 *Performance Measurement Intervals*— System performance measurement techniques should be standardized so that performance measurement tests may be readily duplicated at specified intervals. Radioscopic examination system performance should be evaluated at sufficiently frequent intervals, as may be agreed upon by the supplier and user of radioscopic examination services, to minimize the possibility of time-dependent performance variations.

6.2.3 *Measurement with Reference Object and IQIs*—Radioscopic examination system performance measurement using IQIs shall be in accordance with Practices E747, E1025, or E1742. The IQIs should be placed at the source side of a reference object as close as possible to the region of interest. The use of wire-type IQIs (see Practice E747) should also take into account the fact that the radioscopic examination system may exhibit asymmetrical sensitivity, in which case the wire axis shall be oriented along the system's axis of least sensitivity. Selection of IQI thickness should be consistent with the part radiation path length thickness. For more details the instructions in the referenced standards shall be followed. The reference object should be placed into the radioscopic examination system in the same position as the actual object and may be manipulated through the same range of motions through a given exposure for dynamic radioscopic systems as are available for the actual object so as to maximize the radioscopic examination system's response to the indications of the IQIs or simulated imperfection.

6.2.4 *Measurement with a Reference Block*—The reference block may be an actual object with known features that are representative of the range of features to be detected, or may be fabricated to simulate the object with a suitable range of representative features. Alternatively, the reference block may be a one-of-a-kind or few-of-a-kind reference object containing known imperfections that have been verified independently. Reference blocks containing known, natural discontinuities are useful on a single-task basis, but are not universally applicable. Where standardization among two or more radioscopic examination systems is required, a duplicate manufactured reference block should be used. The reference blocks should approximate the object as closely as is practical, being made of the same material with similar dimensions and features in the radioscopic examination region of interest. Manufactured reference blocks should include features at least as small as those that must be reliably detected in the actual objects in locations where they are expected to occur in the actual object. Where features are internal to the object, it is permissible to produce the reference block in sections. Reference block details are a matter of agreement between the user and supplier of radioscopic examination services.

6.2.4.1 *Use of a Reference Block*—The reference block should be placed into the radioscopic examination system in the same position as the actual object and may be manipulated through the same range of motions through a given exposure for dynamic radioscopic systems as are available for the actual object so as to maximize the radioscopic examination system's response to the simulated imperfection.

6.2.4.2 *Radioscopic Examination Techniques*— (radiation beam energy, intensity, focal spot size, enlargement, digital image processing parameters, manipulation scan plan for dynamic radioscopic systems, scanning speed, and other system variables) utilized for the reference block shall be identical to those used for the actual examination of the object.

6.2.5 *Measurement with Step Wedge Method:*

6.2.5.1 An unsharpness gauge and a step wedge with IQIs may be used, if so desired, to determine and track radioscopic system performance in terms of unsharpness and contrast sensitivity. The step wedge shall be placed into the radioscopic examination system in the same position as the actual object with the face of the IQIs to the source side. In minimum two views shall be recorded. Between both views the step wedge shall be rotated by 90° as radioscopic examination system may exhibit asymmetrical sensitivity.

6.2.5.2 The step wedge shall be made of the same material as the test part with in minimum three steps. The thickest and thinnest steps represent the thickest and the thinnest material sections to be examined. Other thickness steps are permissible upon agreement between the provider and the user of radioscopic services. As a minimum, an IQI each representing the required image quality shall be placed on the thinnest and thickest step of the stepwedge. Selection of the IQI shall be in agreement between the CEO and user of radioscopic system. If no quality level is defined 2-2T shall be taken for both, the thinnest and thickest step. See Guide E94 or Practice E1025 for more details about quality levels.

6.2.5.3 The total system unsharpness shall be checked with an IQI of the duplex wire type in accordance with Practice E2002. The duplex wire shall be placed on the second thinnest step of the step wedge tilted by about 5°. The step wedge shall be positioned horizontally and vertically to the lines of the detection system. The duplex wire IQI shall be read in the unsharper direction if any. When agreed between the CEO and the user of radioscopic services a calibrated line pair test pattern may be used instead of the Practice E2002 duplex wire. The line pair test pattern shall be placed on the thinnest step of the wedge. For systems with an image processing computer, the profile across the IQI shall be evaluated. For Practice E2002, the duplex wire pair for which the modulation depth is less than 20 % shall be documented, also noting the actual modulation measured. If using the line pair test pattern, the spatial resolution just before the lines are completely blurred shall be documented. For example where modulation is either just observed or measured, that spatial resolution shall be recorded. Note that with the use of a line pair gauge the lines can sometimes come back into focus at a higher frequency. This resolution is not to be recorded, as this represents an aliased, non-realistic definition of the spatial resolution of the system.

6.2.5.4 A system that exhibits an unsharpness of 320 µm, equivalent to a 160 µm effective pixel pitch, a thin-section contrast sensitivity of 2-4T, and a thick-section contrast sensitivity of 2-2T may be said to have an equivalent performance level of 2-4T – 2-2T – 320 µm. This may be converted to older definitions by: 320 µm ~3 lp/mm; 2-4T ~ 2.8 % equivalent IQI sensitivity; 2-2T ~ 2.0 % equivalent IQI sensitivity to an equivalent performance level of 3 % – 2 % – 3 lp/mm. For more details in converting the contrast levels refer to Practice E1742.

6.2.5.5 The step wedge with the IQIs may be used to make more frequent periodic system performance checks than required in accordance with 6.2.2. Unsharpness and contrast sensitivity checks shall be correlated with IQI readout of reference object performance measurements. This may be done by first evaluating system measurement in accordance with 6.2.3 and immediately thereafter determining the equivalent spatial resolution and contrast sensitivity values.

6.2.6 *Importance of Proper Environmental Conditions*—Environmental conditions conducive to human comfort and concentration will promote examination efficiency and reliability, and must be considered in the performance of visual evaluation radioscopic examination systems. A proper examination environment will take into account temperature, humidity, dust, lighting, access, and noise level factors. Proper reduced lighting intensity is extremely important to provide for high-contrast glare-free viewing of radioscopic examination images.

7. Radioscopic Examination Interpretation and Acceptance Criteria

7.1 *Interpretation*—Interpretation may be done either by an operator in a visual evaluation radioscopic environment, or by means of a computer and appropriate software in the case of an automated radioscopic examination system. A hybrid environment may also be utilized whereby the computer and software presents to the operator a recommended interpretation, which is then subject to the operator's final disposition.

7.2 *Operator*—The supplier and user should reach an agreement as to operator qualifications including duty and rest periods. Nationally or internationally recognized NDT personnel qualification practices or standards such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, or similar document sets forth three levels of nondestructive testing personnel qualifications that the radioscopic examination practitioner may find useful.

7.3 *Accept/Reject Criteria*—Accept/reject criteria is a matter of contractual agreement between the provider and the user of radioscopic examination services.

8. Records, Reports, and Identification of Accepted Material

8.1 Records and reports are a matter of agreement between the supplier and the user. If an examination record archiving requirement exists, refer to 6.1.8, which outlines the necessary information that should be a part of an archival examination record.

9. Safety Conditions

9.1 Radioscopic examination procedures shall be conducted under protective conditions so that personnel will not receive radiation dose levels exceeding that permitted by company, city, state, or national regulations. The recommendations of the National Committee on Radiation Protection should be the guide to radiation safety.

10. Keywords

10.1 analog; detector; digital; display; examination; image; manipulator; processor; radioscopy; source

ANNEX

(Mandatory Information)

A1. DEPARTMENT OF DEFENSE CONTRACTS, SUPPLEMENTAL REQUIREMENTS

A1.1. Scope

A1.1.1 *Purpose*—This annex is to be used in conjunction with Practices E1255 and E1742. It permits the use of and gives guidance on the implementation of radioscopic examination for materials, components, and assemblies, when specified in the contract documents. The radioscopic requirements described herein allow the use of radioscopy for new applications as well as to replace radiography when examination coverage, greater throughput, or improved examination economics can be obtained, provided a satisfactory level of image quality can be demonstrated.

A1.1.2 *Application*— This annex provides guidelines for a written practice as required in 3.2 and 5.2.1 of Practice E1255. Should the requirements in this annex conflict with any other requirements of Practice E1255, then Annex A1 takes precedence. The requirements of this annex are intended to control the quality of the radioscopic examination and not to specify the accept/reject criteria for the object. Accept/reject criteria are provided in other contract documents.

A1.2. Referenced Documents

A1.2.1 In addition to those documents referenced in Practice E1255, the following standards are applicable to the extent specified herein.

A1.2.2 *ASTM Standards:*

E1411 Practice for Qualification of Radioscopic Systems

E1453 Guide for Storage of Magnetic Tape Media that Contains Analog or Digital Radioscopic Data

E1742 Practice for Radiographic Examination

A1.2.3 *Military Standard:*

DOD-STD-2167 Defense System Software Development

A1.2.4 *American Welding Society Standard:*

ANSI/AWS A3.0 Welding Terms and Definitions

A1.2.5 *AIA Standard:*

NAS-410 NAS Certification and Qualification of Nondestructive Test Personnel

A1.2.6 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

A1.3 Government Standards

A1.3.1 Unless otherwise stated, the issues of these documents are those listed in the Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the contract document.

A1.4 Order of Precedence

A1.4.1 In the event of conflict between the text of this document and the references listed in A1.2.2, this document shall take precedence. However, nothing in this document shall supersede applicable laws and regulations unless a specific exemption has been obtained from the cognizant authorities.

A1.5. Terminology

A1.5.1 *component*—the part or parts described, assembled, or processed to the extent specified by the drawing.

A1.5.2 *contracting agency*—a prime contractor, subcontractor, or government agency that procures radioscopic examination services.

A1.5.3 *contract documents*—the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A1.5.4 *mandatory radioscopic examination*—those radioscopic examinations which are a part of the required radiographic examinations specified in the contract documents.

A1.5.5 *NDT facility*—the organization that is responsible for the providing of nondestructive examination services.

A1.5.6 *optional radioscopic examination*—those radioscopic examinations which are conducted for process verification or information only and are not a part of the required radiographic examination specified in the contract documents.

A1.5.7 *prime contractor*—a contractor having responsibility for the design control and delivery to the department of defense for system/equipment such as aircraft, engines, ships, tanks, vehicles, guns and missiles, ground communications and electronic systems, ground support, and test equipment.

A1.5.8 *examination object*—the material, component or assembly that is the subject of the radioscopic examination.

A1.5.9 *written procedure*—in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopic system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopic examination. The development of a radioscopic technique usually precedes the preparation of a written procedure.

A1.5.10 Other definitions not given herein shall be as specified in Terminology E1316.

A1.6 General Requirements

A1.6.1 *Equipment Qualification*—Radioscopic system qualification shall be in accordance with Practice E1411 and can best be evaluated with IQIs similar to the flaw type being investigated. A common IQI is described in Practice E1742.

A1.6.2 *Personnel Qualification*—Radioscopic personnel shall be qualified and certified in accordance with the general requirements of personnel qualification practices or standards such as ANSI/ANST CP-189, SNT-TC-1A, or NAS-410, until specific requirements for radioscopy are included. Radioscopic system qualification, the development of radioscopic examination techniques, scan plans, and the overall implementation of radioscopic examination in accordance with this annex, shall be under the control and supervision of a qualified NAS-410 Level III with additional radioscopy training and experience or in conjunction with an individual having the necessary training and experience in radioscopic examination.

A1.6.3 *Safety*—The performance or radioscopic examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopic procedures shall be performed in a safe manner, such that personnel in that area are not exposed to any radiation dosage and shall in no case exceed Federal, state, and local limits.

A1.6.4 *Archival Recording of Mandatory Radioscopic Examination*—When required by contractual agreement, the radioscopic examination record shall contain the results of mandatory radioscopic examinations. The radioscopic examination record shall be suitably archived for a period of time not less than five years from the examination date or as may otherwise be required in the contract documents. Efficient radioscopic examination record recall shall be available at any time over the record retention period. The radioscopic examination record shall be traceable to the object (by serial number or other means) or to the batch or lot number, if examined in groups. Mandatory radioscopic examinations shall be specified in the contract documents. The optional radioscopic examinations are not specified in the contract documents.

A1.6.4.1 *Radioscopic Examination Record*—The recorded radioscopic examination record for mandatory examinations shall include the written results of the radioscopic examination and the radioscopic image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopic image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopic examination results and, if necessary, the repeating of the radioscopic examination.

A1.6.4.2 *Image Recording Media*—The radioscopic image shall be recorded on a media that is appropriate to the radioscopic examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopic image shall provide an image quality, at least equal to that, for which the radioscopic system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The radioscopic image record shall be maintained in an operable condition for the duration of the record storage period, measured from the date when the last radioscopic image was recorded.

A1.6.4.3 *Recording Media Storage Conditions*—Media storage and handling shall be in accordance with Guide E1453.

A1.6.5 *Image Quality Indicators*—Image quality indicators must be chosen with care to demonstrate the radioscopic system's ability to detect discontinuities or other features that are of interest. Practices E1742, E1025 plaque-type, and E747 wire-type IQIs and reference blocks with real or simulated discontinuities, to match the application, are all acceptable unless a particular IQI is specified in the contract documents. The selected IQI or reference block shall be detailed in the written procedure. An IQI or reference block may not be required for the following radioscopic examinations:

A1.6.5.1 When conducting radioscopy to check for adequate defect removal or grind-out, the final acceptance radioscopic examination shall include an IQI,

A1.6.5.2 Examinations to show material details or contrast between two or more dissimilar materials, in component parts or assemblies, including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material,

A1.6.5.3 Examinations of electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires or connectors, and potted assemblies for broken internal components or missing potting compound,

A1.6.5.4 Optional radioscopic examinations, and

A1.6.5.5 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A1.6.6 *Classification of Examination Object Zones for Radioscopy*—The classification of objects into zones for various accept/reject criteria shall be determined from the contract documents.

A1.7 Detailed Requirements

A1.7.1 *Application Qualification:*

A1.7.1.1 *New Applications*—Radioscopy may be used where appropriate for new examination requirements, provided the required performance, including image quality, can be met.

A1.7.1.2 *Replacement of Existing Radiographic Applications*—When agreed to by the contracting officer, radioscopy may be used to replace or augment existing radiographic applications, provided that the radioscopic results correlate favorably with the results obtained with X-ray film produced in accordance with Practice E1742. Favorable correlation means that the radioscopic and film images show similar sensitivity to object features that are of interest.

A1.7.2 *Written Procedure*—It shall be the responsibility of the NDT facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the object. An object scan plan for dynamic radioscopic systems, meeting the requirements of Practice E1255, (see 5.2.1.2) shall be included in the written procedure. Those portions of the contract document that specify and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be approved by the Level III of the NDT facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A1.7.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, position(s) of the detector, and applicable IQI for each and all variations of the object orientation and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems,

A1.7.2.2 A physical description of the object, including size, thickness, weight, and composition,

A1.7.2.3 Classification of the object into zones for radioscopy,

A1.7.2.4 Examination part masking, if used, for each required view,

A1.7.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the object source side, for each required view,

A1.7.2.6 Detector field of view for each required view,

A1.7.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector, for each required view,

A1.7.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view,

A1.7.2.9 Added beam filtration, if used, for each required view,

A1.7.2.10 The examination geometry and coverage for each required view,

A1.7.2.11 Type of IQI or reference block used and the required quality level,

A1.7.2.12 All hardware and software settings that can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera and display settings and image processor variables, and

A1.7.2.13 The recording media and storage image format for mandatory radioscopic image storage.

A1.7.3 *Object Examination*—The number of objects to be examined and the coverage required for each object shall be specified in the contract documents. If not specified, all objects shall receive 100 % radioscopic coverage as detailed in the written procedure.

A1.7.4 *Image Quality*— Unless otherwise specified in the contract documents, the required image quality level is 2-2T. Image quality assessment shall be performed using the same system parameters as in the examination and as documented in the written procedure.

A1.7.4.1 The IQI may be placed on the object or on a mounting block, at or near the object location, following the requirements of Practice E1742. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the object examination. Batch quantities of similar parts need not have IQI images made between each part, at the discretion of the Level III. The radioscopic examination results shall be invalid, if the before and after IQI images fail to demonstrate the required sensitivity. The before and after IQI images shall be considered a part of the object image for radioscopic image interpretation and archiving purposes.

A1.7.4.2 With written permission from the contracting agency, other IQI's or a reference block with natural or artificial flaws may be used instead of the specified IQI.

A1.7.5 *Radioscopic System Qualification*—The radioscopic system, including mandatory radioscopic image archiving devices, shall be qualified to the image quality level required for object examination. Radioscopic system initial qualification shall be in accordance with Practice E1411.

A1.7.6 *Radioscopic System Requalification*—The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance. Each requalification shall be carried out in accordance with Practice E1411.

A1.7.7 *Examination Image Control*—The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any changes in system performance requiring changes in operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A1.7.8 *Repair of Radioscopic System*—Repair or replacement of key radioscopic system components including, but not limited to, the radiation source, image forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file until the completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A1.7.9 *Image Interpretation:*

A1.7.9.1 *Static Imaging*— Radioscopic system qualification in accordance with Practice E1411 applies to static imaging conditions only where the examination part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A1.7.9.2 *Dynamic Imaging*— Dynamic or in-motion imaging may be used to gain useful information about the object. However, unless dynamic imaging is specified, the final assessment of image formation for mandatory radioscopic examinations shall be made in the static mode. When the contracting agency specifies dynamic examination, all aspects of the procedure must be approved by NAS-410 Level III personnel. For dynamic examination, the image quality shall be measured under the same procedure as the examination.

A1.7.10 *Feature Size Determination*—Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A1.7.10.1 *Feature Measurement by Examination Object Displacement*—For those radioscopic systems with calibrated manipulation systems, the more accurate, and therefore preferred, method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A1.7.10.2 *Feature Measurement by Comparison*—A second method involves comparing the object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A1.7.11 *Gray Scale Range*—The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the object or IQI material.

A1.7.12 *Timing of Radioscopic Examination*—Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A1.7.13 *Identification*— A means shall be provided for the positive identification of the object to the archival radioscopic examination record. Archived radioscopic images shall be annotated to agree with the object identification.

A1.7.14 *Locating the Radioscopic Examination Areas*—Whenever more than one image is required for a weldment or other object, location markers shall be placed on the object in order that the orientation of the object and the location of object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the part orientation is obvious and coverage is not in question.

A1.7.15 *Surface Preparation*—Examination objects may be examined without surface preparation, except when required to remove surface conditions that may interfere with proper interpretation of the radioscopic image or that may create a safety hazard.

A1.7.16 *Detailed Data*— The provider of radioscopic examination services shall keep the written procedure, qualification documentation, and the signed examination reports or tabulated results, or both, for five years from the radioscopic examination date, unless otherwise specified in the contract documents. For software-based automated radioscopic systems using custom software, a copy of the source code and the related examination parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages or to traceable software documentation which complies with DOD-STD-2167 where a separate copy of the software is maintained.

A1.7.17 *Radioscopic Reexamination of Repairs*—When repair has been performed as the result of radioscopic examination, the repaired areas shall be reexamined using the same radioscopic technique to evaluate the effectiveness of the repair. Each repaired area shall be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A1.7.18 *Retention of Radioscopic Examination Records*—Mandatory radioscopic examination records and associated radioscopic images shall be stored in a proper repository at the contractor's plant for five years from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A1.7.19 *Rejection of Objects*—Examination objects containing discontinuities exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A1.7.20 *Reexamination*— Where there is a reasonable doubt as to the ability to interpret the radioscopic results because of improper execution or equipment malfunction, the object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDT facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with to Practice E1411.

A1.7.21 *Examination Object Marking*—The marking of objects shall be as specified in E1742.

A1.8 Notes

A1.8.1 This section contains information of a general or explanatory nature and is not mandatory. (**Warning—**Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopic examinations should cause no problem, extended periods of radiation exposure should be avoided.)

A1.8.1.1 *Human Factors*— The success of radioscopic examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopic image interpretation.

A1.8.1.2 *Use of IQI(s)*— As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all discontinuities down to the minimum defect size. This is due to the fact that many discontinuities, especially those of a planar nature, are very orientation sensitive. When using dynamic radioscopic systems, care must be taken to see that the scan plan includes sufficient manipulation to maximize the possibility that orientation-sensitive discontinuities will be found. It is for this reason that the use of reference blocks with real or simulated discontinuities may more accurately characterize the ability of the radioscopic system to find orientation-sensitive discontinuities when using dynamic radioscopic systems.

A1.8.1.3 *Use of Image-Processing Techniques*—Care should be exercised in applying digital image-processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range, while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects, whereby features in one direction are emphasized while those in the orthogonal direction are de-emphasized. Such cautions are intended to cause the careful evaluation of digital image-processing techniques and not to discourage their use.

A1.8.1.4 *Feature Size Determination*—As with radiography, great care must be exercised in trying to assess part feature dimensions from a two-dimensional projected view.

STANDARD PRACTICE FOR RADIOSCOPIC EXAMINATION OF WELDMENTS

(19) SE-1416

(Identical with ASTM Specification E1416-16a.)

Standard Practice for Radioscopic Examination of Weldments

1. Scope

1.1 This practice covers a uniform procedure for radioscopic examination of weldments. Requirements expressed in this practice are intended to control the quality of the radioscopic images and are not intended for controlling acceptability or quality of welds.

1.2 This practice applies only to the use of equipment for radioscopic examination in which the image is finally presented on a display screen (monitor) for operator evaluation. The examination may be recorded for later review. It does not apply to fully automated systems where evaluation is automatically performed by computer.

1.3 The radioscopic extent, the quality level, and the acceptance criteria to be applied shall be specified in the contract, purchase order, product specification, or drawings.

1.4 This practice can be used for the detection of discontinuities. This practice also facilitates the examination of a weld from several directions, such as perpendicular to the weld surface and along both weld bevel angles. The radioscopic techniques described in this practice provide adequate assurance for defect detectability; however, it is recognized that, for special applications, specific techniques using more stringent requirements may be needed to provide additional detection capability. The use of specific radioscopic techniques shall be agreed upon between purchaser and supplier.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E94 Guide for Radiographic Examination
E543 Specification for Agencies Performing Nondestructive Testing
E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
E1000 Guide for Radioscopy
E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E1032 Test Method for Radiographic Examination of Weldments
E1255 Practice for Radioscopy
E1316 Terminology for Nondestructive Examinations
E1411 Practice for Qualification of Radioscopic Systems
E1453 Guide for Storage of Magnetic Tape Media that Contains Analog or Digital Radioscopic Data
E1475 Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data
E1647 Practice for Determining Contrast Sensitivity in Radiology
E1742 Practice for Radiographic Examination
E2002 Practice for Determining Total Image Unsharpness and Basic Spatial Resolution in Radiography and Radioscopy
E2033 Practice for Computed Radiology (Photostimulable Luminescence Method)
E2698 Practice for Radiological Examination Using Digital Detector Arrays

2.2 *ASNT Standards:*

ASNT Recommended Practice No. SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing
ANSI/ASNT CP-189-ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *National Aerospace Standard:*

NAS 410 Certification and Qualification of Nondestructive Test Personnel

2.4 *Other Standards:*

ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

SMPTE RP 133 Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard-Copy Recording Cameras

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms applicable to this practice may be found in Terminology E1316.

4. Apparatus

4.1 Success of the radioscopic process depends on the overall system configuration and the selection of appropriate subsystem components. Guidance on the selection of subsystem components and the overall system configuration is provided in Guide E1000 and Practice E1255. Guidance on the initial qualification and periodic re-qualification of the radioscopic system is provided in Practice E1411. The suitability of the radioscopic system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein; unless otherwise specified by the cognizant engineering organization, the default image quality level shall be 2-2T.

4.2 *Radiation Source (X-ray or Gamma-ray)*—Selection of the appropriate source is dependent upon variables regarding the weld being examined, such as material composition and thickness. The suitability of the source shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the radiation source may be found in Guide E1000 and Practice E1255.

4.3 *Manipulation System*—Selection of the appropriate manipulation system (where applicable) is dependent upon variables such as the size and orientation of the object being examined and the range of motions, speed of manipulation, and smoothness of motion. The suitability of the manipulation system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the manipulation system may be found in Practice E1255.

4.4 *Imaging System*—Selection of the appropriate imaging system is dependent upon variables such as the size of the object being examined and the energy and intensity of the radiation used for the examination. The suitability of the imaging system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of an imaging system may be found in Guide E1000 and Practice E1255.

4.5 *Image Processing System*—Where agreed between purchaser and supplier, image processing systems may be used for noise reduction through image integration or averaging, contrast enhancement and other image processing operations.

4.6 *Collimation*—Selection of appropriate collimation is dependent upon the geometry of the object being examined. It is generally useful to select collimation to limit the primary radiation beam to the weld and the immediately adjacent base material in order to improve radioscopic image quality.

4.7 *Filters and Masking*—Filters and masking may be used to improve image quality from contrast reductions caused by low-energy scattered radiation. Guidance on the use of filters and masking can be found in Guide E94.

4.8 *Image Quality Indicators (IQI)*—Unless otherwise specified by the applicable job order or contract, image quality indicators shall comply with the design and identification requirements specified in Practices E747, E1025, E1647, E1742, or E2002.

4.9 *Shims, Separate Blocks, or Like Sections*—Shims, separate blocks, or like sections made of the same or radioscopically similar materials (as defined in Practice E1025) may be used to facilitate image quality indicator positioning as described in 9.10.3. The like section should be geometrically similar to the object being examined.

4.10 *Location and Identification Markers*—Lead numbers and letters should be used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radioscopic technique to discern the markers on the images. As a general rule, markers from 0.06 to 0.12 in. (1.5 to 3 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and iridium^{192} radioscopy. For higher energy (greater than 1 MeV and cobalt^{60}) radioscopy, it may be necessary to use markers that are thicker (0.12 in. (3 mm) thick or more). In cases where the system being used provides a display of object position within the image, this shall be acceptable as identification of object location. In case of digital storage of the images, digital markers and annotations in the image may be used if they are stored permanently with the image.

5. Materials

5.1 *Recording Media*—Recording media for storage of images shall be in a format agreed by the purchaser and supplier. This may include either analog or digital media.

6. Basis of Application

6.1 *Personnel Qualification* —NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS 410, ISO 9712, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.3 *Performance Measurement*—Radioscopic examination system performance parameters must be determined initially and monitored regularly to ensure consistent results. The best measure of total radioscopic examination system performance can be made with the system in operation, using a test object similar to the test part under actual operating conditions. This indicates the use of an actual or simulated test object or calibration block containing actual or simulated features that must be detected reliably. Such a calibration block will provide a reliable indication of the radioscopic examination system's capabilities. Conventional wire or plaque-type image quality indicators (IQIs) may be used in place of, or in addition to, the simulated test object or calibration block. Performance measurement methods are subject to agreement between the purchaser and the supplier of radioscopic examination services; if no special agreements are done the performance shall be measured in accordance with 6.3.2, 6.3.3, 6.3.4 or combinations thereof, or Practice E1411 or Appendix X1 of E1255.

6.3.1 *Performance Measurement Intervals*—System performance measurement techniques should be standardized so that performance measurement tests may be duplicated readily at specified intervals. Radioscopic examination performance should be evaluated at sufficiently frequent intervals, as may be agreed upon between the purchaser and the supplier of radioscopic examination services, in order to minimize the possibility of time-dependent performance variations.

6.3.2 *Measurement with IQIs*—System performance measurements using IQIs shall be in accordance with accepted industry standards describing the use of IQIs. The IQIs should be placed on the radiation source side of the test object, as close as possible to the region of interest. The use of wire IQIs should also take into account the fact that the radioscopic examination may exhibit asymmetrical sensitivity, in which case the wire diameter axis shall be oriented along the system's axis of least sensitivity. Selection of IQI thickness should be consistent with the test part radiation path length.

6.3.3 *Measurement With a Calibration Block*—The calibration block may be an actual test part with known features that are representative of the range of features to be detected, or it may be fabricated to simulate the test object with a suitable range of representative features. Alternatively, the calibration block may be a one-of-a-kind or few-of-a-kind reference test object containing known imperfections that have been verified independently. Calibration blocks containing known, natural defects are useful on a single-task basis, but they are not universally applicable. A duplicate manufactured calibration block should be used where standardization among two or more radioscopic examination systems is required. The calibration blocks should approximate the test object as closely as is practical, being made of the same material with similar dimensions and features in the radioscopic examination region of interest. Manufactured calibration blocks shall include features at least as small as those that must be detected reliably in the actual test object in locations where they are expected to occur. It is permissible to produce the calibration block in sections where features are internal to the test object. Calibration block details are a matter of agreement between the purchaser and the supplier of radioscopic examination services.

6.3.3.1 *Use of a Calibration Block*—The calibration block shall be placed in the radioscopic examination system in the same position as the actual test object. The calibration block may be manipulated through the same range of motions as are available for the actual test object so as to maximize the radioscopic examination system's response to the simulated imperfections.

6.3.3.2 *Radioscopic Examination Techniques*—Techniques used for the calibration block shall be identical to those used for actual examination of the test part. Technique parameters shall be listed and include, as a minimum, radiation beam energy, intensity, focal spot size, enlargement, digital image processing parameters, manipulation scan plan, and scanning speed.

6.3.4 *Use of Calibrated Line Pair Test Pattern and Step Wedge*—A calibrated line pair test pattern and step wedge may be used, if desired, to determine and track the radioscopic system performance in terms of unsharpness and contrast sensitivity. The line pair test pattern is used without an additional absorber to evaluate system unsharpness (see Practices E1411 and E2002). The step wedge is used to evaluate system contrast sensitivity (see Practice E1647).

6.3.4.1 The step wedge must be made of the same material as the test part, with steps representing 100, 99, 98, 97, and 96 % of both the thickest and thinnest material sections to be examined. The thinner steps shall be adjacent to the 100 % thickness in order to facilitate discerning the minimum visible thickness step. Other thickness steps are permissible upon agreement between the purchaser and the supplier of radioscopic examination services.

6.3.4.2 The line pair test pattern and step wedge tests shall be conducted in a manner similar to the performance measurements for the IQI or calibration block. It is permissible to adjust the X-ray energy and intensity to obtain a usable line pair test pattern image brightness. In the case of a radioisotope or X-ray generating system in which the energy or intensity cannot be adjusted, additional filtration may be added to reduce the brightness to a useful level. Contrast sensitivity shall be evaluated at the same energy and intensity levels as are used for the radioscopic technique.

6.3.4.3 A system that exhibits a thin section contrast sensitivity of 3 %, a thick section contrast sensitivity of 2 %, and an unsharpness of 3 line pairs/mm may be said to have a quality level of 3 % – 2 % – 3 lp⁄mm. A conversion table from duplex wire read out to lp/mm can be found in Practices E1411 or E1255.

6.3.4.4 The line pair test pattern and step wedge may be used to make more frequent periodic system performance checks than are required in 6.3.1. Resolution and contrast sensitivity checks must be correlated with IQI or calibration block performance measurements. This may be accomplished by first evaluating the system performance in accordance with

6.3.2 or 6.3.3 and immediately thereafter determining the equivalent unsharpness and contrast sensitivity values.

6.4 *Time of Examination*—The time of examination shall be in accordance with 9.1 unless otherwise specified.

6.5 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as described in this practice unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6.6 *Extent of Examination*—The extent of examination shall be in accordance with 8.3 unless otherwise specified.

6.7 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 10 unless otherwise specified. Acceptance criteria shall be specified in the contractual agreement.

6.8 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this practice and if required shall be specified in the contractual agreement.

7. Safety

7.1 Radioscopic procedures shall comply with applicable city, state, and federal safety regulations.

8. Requirements

8.1 *Procedure Requirement*—Unless otherwise specified by the applicable job order or contract, radioscopic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of the written procedures shall be as agreed by purchaser and supplier. The production procedure shall address all applicable portions of this practice and shall be available for review during interpretation of the images. The written procedure shall include the following:

8.1.1 Material and thickness range to be examined,

8.1.2 Equipment to be used, including specifications of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera black level, gain, look-up table (LUT), type of display monitor),

8.1.3 Examination geometry, including source-to-object distance, object-to-detector distance and orientation,

8.1.4 Image quality indicator designation and placement,

8.1.5 Test-object scan plan, indicating the range of motions and manipulation speeds through which the test object shall be manipulated in order to ensure satisfactory results (see description in 6.2.1.2 of Practice E1255),

8.1.6 Image-processing parameters,

8.1.7 Image-display parameters,

8.1.8 Image storage, and

8.1.9 Plan for system qualification and periodic requalification as described in Practices E1255 and E1411.

8.2 *Radioscopic Coverage*—Unless otherwise specified by purchaser and supplier agreement, the extent of radioscopic coverage shall include 100 % of the volume of the weld and the adjacent base metal.

8.3 *Examination Speed*—For dynamic examination, the speed of object motion relative to the radiation source and detector shall be controlled to ensure that the required radioscopic quality level is achieved.

8.4 *Radioscopic Image Quality*—All images shall be free of artifacts that could mask or be confused with the image of any discontinuity in the area of interest. It may be possible to prevent blemishes from masking discontinuities or being confused with discontinuities by moving the object being examined relative to the imaging device. If any doubt exists as to the true nature of an indication exhibited in the image, the image shall be rejected and a new image of the area shall be made.

8.5 *Radioscopic Quality Level*—Radioscopic quality level shall be determined upon agreement between the purchaser and supplier and shall be specified in the applicable job order or contract. If no quality level is defined, 2-2T shall be the standard. Radioscopic quality shall be specified in terms of equivalent penetrameter (IQI) sensitivity and shall be measured using image quality indicators conforming to Practices E747, E1025, or E1742. Additionally, for system unsharpness measurement, the Practice E2002 duplex wire gauge should be used.

8.6 *Acceptance Level*—Accept and reject levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.7 *Image-Viewing Facilities*—Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflection, shadows, or glare on the image. The image display performance, size, and placement are important radioscopic system considerations. A test pattern similar to SMPTE RP133 shall be used to qualify the display.

8.8 *Storage of Images*—When storage is required by the applicable job order or contract, the images should be stored in a format stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement. The image-storage duration and location shall be as agreed between purchaser and supplier (see Guides E1453 and E1475).

9. Procedure

9.1 *Time of Examination*—Unless otherwise specified by the applicable job order or contract, perform radioscopy prior to heat treatment.

9.2 *Surface Preparation*—Unless otherwise agreed upon, remove the weld bead ripple or weld-surface irregularities on both the inside and outside (where accessible) by any suitable process so that the image of the irregularities cannot mask, or be confused with, the image of any discontinuity. Interpretation can be optimized if surface irregularities are removed such that the image of the irregularities is not discernible.

9.3 *System Unsharpness*—System unsharpness should be measured using Practice E2002 duplex wire IQI (see also Guide E1000). System Unsharpness (U_{im}) is defined as total unsharpness (U_{total}) divided by magnification (v) (see Guide E1000):

$$U_{im} = U_{total} / v \quad (1)$$

Unless otherwise specified in the applicable job order or contract, U_{im} shall not exceed the following:

TABLE Unsharpness (U_{im}) (Maximum)

Material Thickness	U_{im}, max, in. (mm)
under 2 in. (50 mm)	0.020 (0.50)
2 through 3 in. (50 through 75 mm)	0.030 (0.75)
over 3 through 4 in. (75 through 100 mm)	0.040 (1.00)
greater than 4 in. (100 mm)	0.070 (1.75)

Discussion: In standards with DDA (E2698), CR (E2033), or film (E1032) the following unsharpness requirement for materials under 1 in. (25.4 mm) thickness is used: Maximum 0.010 in. (0.254 mm).

9.4 *Examination Speed*—For dynamic examination, determine the speed of object motion relative to the radiation source and detector upon agreement between the purchaser and supplier. Base this determination upon the achievement of the required radioscopic quality level at that examination speed.

9.5 *Direction of the Radiation*—Direct the central beam of radiation perpendicularly toward the center of the effective area of the detector or to a plane tangent to the center of the image, to the maximum extent possible, except for double-wall exposure-double-wall viewing elliptical projection techniques, as described in 9.14.2.

9.6 *Scattered Radiation*—Scattered radiation (radiation scattered from the test object and from surrounding structures) reduces radioscopic contrast and may produce undesirable effects on radioscopic quality. Use precautions such as collimation of the source, collimation of the detector, and additional shielding as appropriate to minimize the detrimental effects of this scattered radiation.

9.7 *Image Quality Indicator Selection*—For selection of the image quality indicator, the thickness on which the image quality indicator is based is the single-wall thickness plus the lesser of the actual or allowable reinforcement. Backing strips or rings are not considered as part of the weld or reinforcement thickness for image quality indicator selection. For any thickness, an image quality indicator acceptable for thinner materials may be used, provided all other requirements for radioscopy are met.

9.8 *Number of Image Quality Indicators:*

9.8.1 Place at least one image quality indicator of Practices E747, E1025, or E1742, and one image quality indicator of Practice E2002 in the area of interest representing an area in which the brightness is relatively uniform. The degree of brightness uniformity shall be agreed upon between purchaser and supplier. If the image brightness in an area of interest differs by more than the agreed amount, use two image quality indicators. Use one image quality indicator to demonstrate acceptable image quality in the darkest portion of the image and use one image quality indicator to demonstrate acceptable image quality in the lightest portion of the image.

9.8.2 When a series of images are made under identical conditions, it is permissible for the image quality indicators to be used only on the first and last images in the series, provided this is agreed upon between the purchaser and supplier. In this case, it is not necessary for the image quality indicators to appear in each image.

9.8.3 Always retain qualifying images, on which one or more image quality indicators were imaged during exposure, as part of the record to validate the required image quality indicator sensitivity and placement.

9.9 *Image Quality Indicator Placement:*

9.9.1 Place the image quality indicator on the source side adjacent to the weld being examined. Where the weld metal is not radioscopically similar to the base material or where geometry precludes placement adjacent to the weld, place the image quality indicator over the weld or on a separate block, as described in 9.10.

9.9.2 *Detector-Side Image Quality Indicators*—In those cases where the physical placement of the image quality indicators on the source side is not possible, place the image quality indicators on the detector side. The applicable job order or contract shall specify the applicable detector-side quality level. The accompanying documents shall clearly indicate that the image quality indicators were located on the detector side.

9.10 *Separate Block*—When configuration or size prevents placing the image quality indicators on the object being examined, use a shim, separate block or like section conforming to the requirements of 4.9 provided the following conditions are met:

9.10.1 The image quality indicator is no closer to the detector than the source side of the object being examined (unless otherwise specified).

9.10.2 The brightness in the area of the image quality indicator including the shim, separate block, or like section and IQI where applicable are similar to the brightness in the area of interest.

9.10.3 The shim, separate block, or like section is placed as close as possible to the object being examined.

9.10.4 When hole-type image quality indicators are used, the shim, separate block, or like section dimensions shall exceed the image quality indicator dimensions such that the outline of at least three sides of the image quality indicator image is visible on the image.

9.11 *Shim Utilization*—When a weld reinforcement or backing ring and strip is not removed, place a shim of material that is radioscopically similar to the backing ring and strip under the image quality indicators to provide approximately the same thickness of material under the image quality indicator as the average thickness of the weld reinforcement plus the wall thickness, backing ring and strip.

9.11.1 *Shim Dimensions and Location*—When hole-type image quality indicators are used, the shim dimensions and location shall exceed the image quality indicator dimensions by at least 0.12 in. (3 mm) on at least three sides. At least three sides of the image quality indicator shall be discernible in accordance with 9.10.4 except that only the two ends of the image quality indicator need to be discernible when located on piping less than 1 in. (25 mm) nominal pipe size. Place the shim so as not to overlap the weld image including the backing strip or ring.

9.11.2 *Shim Image Brightness*—The brightness of the shim image shall be similar to the image brightness of the area of interest.

9.12 *Location Markers*—Place location markers outside the weld area. The radioscopic image of the location markers for the identification of the part location with the image shall appear on the image without interfering with the interpretation and with such an arrangement that it is evident that complete coverage was obtained.

9.12.1 *Double-Wall Technique*—When using a technique in which radiation passes through two walls and the welds in both walls are simultaneously viewed for acceptance, and the entire image of the object being examined is displayed, only one location marker is required in the image.

9.12.2 *Series of Images*—For welds that require a series of images to cover the full length or circumference of the weld, apply the complete set of location markers at one time, wherever possible. A reference or zero position for each series must be identified on the component. A known feature on the object (for example, keyway, nozzle, and axis line) may also be used for establishment of a reference position. Indicate this feature on the radioscopic record.

9.12.3 *Similar Welds*—On similar type welds on a single component, the sequence and spacing of the location markers must conform to a uniform system that shall be positively identified in the radioscopic procedure or interpretation records. In addition, reference points on the component will be shown on the sketch to indicate the direction of the numbering system.

9.13 *Image Identification*—Provide a system of positive identification of the image. As a minimum, the following shall appear on the image: the name or symbol of the company performing radioscopy, the date, and the weld identification number traceable to part and contract. Identify subsequent images made of a repaired area with the letter “R”.

9.14 *Radioscopic Techniques:*

9.14.1 *Single-Wall Technique*—Except as provided in 9.14.2 – 9.14.4, perform radioscopy using a technique in which the radiation passes through only one wall.

9.14.2 *Double-Wall Technique for Circumferential Welds*—For circumferential welds 4 in. (100 mm) outside diameter (3.5 in. (88 mm) nominal pipe size) or less, use a technique in which the radiation passes through both walls and both walls are viewed for acceptance on the same image. Unless otherwise specified, either elliptical or superimposed projections may be used. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld, agreement between contracting parties must specify necessary weld coverage.

9.14.3 For circumferential welds greater than 4 in. (100 mm) outside diameter (3.5 in. (88 mm) nominal pipe size), use a technique in which only single-wall viewing is performed. A sufficient number of views should be taken to examine the entire-weld. Where design or access restricts a practical technique from examining the entire weld, agreement between contracting parties must specify necessary weld coverage.

9.14.4 For radioscopic techniques that prevent single-wall exposures due to restricted access, such as jacketed pipe or ship hull, the technique should be agreed upon in advance between the purchaser and supplier. It should be recognized that image quality indicator sensitivities based on single-wall thickness may not be obtainable under some conditions.

10. Records

10.1 Maintain the following radioscopic records as agreed between purchaser and supplier:

10.1.1 Radioscopic standard shooting sketch, including examination geometry, source-to-object distance, object-to-detector distance and orientation,

10.1.2 Material and thickness range examined,

10.1.3 Equipment used, including specification of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera blacklevel, gain, LUT, display, and so forth) and display parameters,

10.1.4 Image quality indicator (and shim, if used) placement,

10.1.5 Test-object scan plan, including ranges of motion and manipulation speeds,

10.1.6 Image processing parameters,

10.1.7 Image-storage data,

10.1.8 Weld repair documentation,

10.1.9 *Image*—Interpretation record shall contain as a minimum the following information:

10.1.9.1 Disposition of each image (acceptable or rejectable),

10.1.9.2 If rejectable, cause for rejection (slag, crack, porosity, and so forth),

10.1.9.3 Surface indication verified by visual examination (grinding marks, weld ripple, spatter, and so forth), and

10.1.9.4 Signature of the image interpreter, including level.

11. Keywords

11.1 gamma ray; nondestructive testing; radioscopic examination; radioscopy; weldments; X-ray

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STANDARD PRACTICE FOR DETERMINING CONTRAST SENSITIVITY IN RADIOLOGY

SE-1647

(Identical with ASTM Specification E1647-09.)

Standard Practice for Determining Contrast Sensitivity in Radiology

1. Scope

1.1 This practice covers the design and material selection of a contrast sensitivity measuring gauge used to determine the minimum change in material thickness or density that may be imaged without regard to spatial resolution limitations.

1.2 This practice is applicable to transmitted-beam radiographic and radioscopic imaging systems utilizing X-ray and gamma ray radiation sources.

1.3 The values stated in inch-pound units are to be regarded as standard. The SI units given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see NIST/ANSI Handbook 114 Section 8, Code of Federal Regulations 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*

B139/B139M Specification for Phosphor Bronze Rod, Bar, and Shapes

B150/B150M Specification for Aluminum Bronze Rod, Bar, and Shapes

B161 Specification for Nickel Seamless Pipe and Tube

B164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E1000 Guide for Radioscopy

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1255 Practice for Radioscopy

E1316 Terminology for Nondestructive Examinations

E1411 Practice for Qualification of Radioscopic Systems

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2445 Practice for Qualification and Long-Term Stability of Computed Radiology Systems

2.2 *Federal Standards:*

21 CFR 1020.40 Safety Requirements for Cabinet X-ray Systems

29 CFR 1910.96 Ionizing Radiation

2.3 *NIST/ANSI Standards:*

NIST/ANSI Handbook 114 General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Ray Sources, Energies to 10 MeV

2.4 *Other Standard:*

EN 462 – 5 Duplex Wire Image Quality Indicator

EN 13068–1 Radioscopic Testing-Part 1: Qualitative Measurement of Imaging Properties

3. Terminology

3.1 *Definitions*—Definitions of terms applicable to this test method may be found in Terminology E1316.

4. Summary of Practice

4.1 It is often useful to evaluate the contrast sensitivity of a penetrating radiation imaging system separate and apart from spatial resolution measurements. Conventional image quality indicators (IQI's), such as Test Method E747 wire and Practice E1025 plaque IQIs, combine the contrast sensitivity and resolution measurements into an overall performance figure of merit, other methods such as included in Practice E2002 do not address contrast specifically. Such figures of merit are often not adequate to detect subtle changes in imaging system performance. For example, in a high contrast image, spatial resolution can degrade with almost no noticeable effect upon overall image quality. Similarly, in an application in which the imaging system provides a very sharp image, contrast can fade with little noticeable effect upon the overall image quality. These situations often develop and may go unnoticed until the system performance deteriorates below acceptable image quality limits.

5. Significance and Use

5.1 The contrast sensitivity gauge measures contrast sensitivity independent of the imaging system spatial resolution limitations. The thickness recess dimensions of the contrast sensitivity gauge are large with respect to the spatial resolution limitations of most imaging systems. Four levels of contrast sensitivity are measured: 4 %, 3 %, 2 %, and 1 %.

5.2 The contrast sensitivity gauge is intended for use in conjunction with a high-contrast resolution measuring gauge, such as the EN 462 – 5 Duplex Wire Image Quality Indicator. Such gauges measure spatial resolution essentially independent of the imaging system's contrast sensitivity. Such measurements are appropriate for the qualification and performance monitoring of radiographic and radioscopic imaging systems with film, realtime devices, Computed Radiography (CR) and Digital Detector Arrays (DDA).

5.3 Radioscopic/radiographic system performance may be specified by combining the measured contrast sensitivity expressed as a percentage with the spatial resolution expressed in millimeters of unsharpness. For the EN 462 – 5 spatial resolution gauge, the unsharpness is equal to twice the wire diameter. For the line pair gauge, the unsharpness is equal to the reciprocal of the line-pair/mm value. As an example, an imaging system that exhibits 2 % contrast sensitivity and images the 0.1 mm EN 462 – 5 paired wires (equivalent to imaging 5 line-pairs/millimeter resolution on a line-pair gauge) performs at a 2 %–0.2 mm sensitivity level. A standard method of evaluating overall radioscopic system performance is given in Practice E1411 and in EN 13068–1 and for CR it can be found in Practice E2445.

6. Contrast Sensitivity Gauge Construction and Material Selection

6.1 Contrast sensitivity gauges shall be fabricated in accordance with Fig. 1, using the dimensions given in Table 1, Table 2, and Table 3.

6.2 The gauge shall preferably be fabricated from the examination object material. Otherwise, the following material selection guidelines are to be used:

6.2.1 Materials are designated in eight groupings, in accordance with their penetrating radiation absorption characteristics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

6.2.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti) are identified 03, 02, and 01, respectively, for their predominant constituent. The materials are listed in order of increasing radiation absorption.

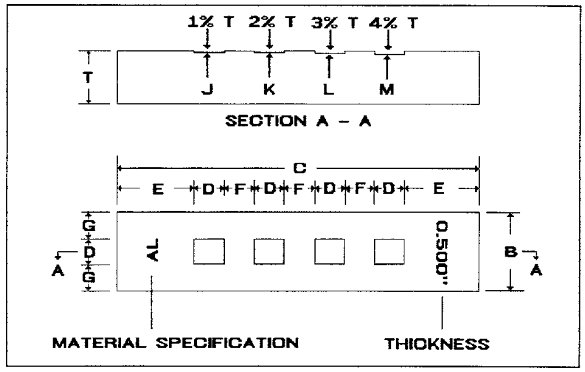

FIG. 1 General Layout of the Contrast Sensitivity Gauge

TABLE 1 Design of the Contrast Sensitivity Gauge

Gauge Thickness	J Recess	K Recess	L Recess	M Recess
T	1 % of T	2 % of T	3 % of T	4 % of T

TABLE 2 Contrast Sensitivity Gauge Dimensions

Gauge Size	B DIM.	C DIM.	D DIM.	E DIM.	F,G DIM.
1	0.750 in.	3.000 in.	0.250 in.	0.625 in.	0.250 in.
	19.05 mm	76.20 mm	6.35 mm	15.88 mm	6.35 mm
2	1.500 in.	6.000 in.	0.500 in.	1.250 in.	0.500 in.
	38.10 mm	152.40 mm	12.70 mm	31.75 mm	12.7 mm
3	2.250 in.	9.000 in.	0.750 in.	1.875 in.	0.750 in.
	57.15 mm	228.60 mm	19.05 mm	47.63 mm	19.05 mm
4	3.000 in.	12.000 in.	1.000 in.	2.500 in.	1.000 in.
	76.20 mm	304.80 mm	25.40 mm	63.50 mm	25.4 mm

TABLE 3 Contrast Sensitivity Gauge Application

Gauge Size	Use on Thicknesses
1	Up to 1.5 in. (38.1 mm)
2	Over 1.5 in. (38.1 mm) to 3.0 in. (76.2 mm)
3	Over 3.0 in. (76.2 mm) to 6.0 in. (152.4 mm)
4	Over 6.0 in. (152.4 mm)

6.2.3 The heavy metals group, steel, copper base, nickel base, and other alloys are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

6.2.4 Common trade names or alloy designations have been used for clarification of pertinent materials.

6.3 The materials from which the contrast sensitivity gauge is to be made is designated by group number. The gauge is applicable to all materials in that group. Material groupings are as follows:

6.3.1 *Materials Group 03:*

6.3.1.1 The gauge shall be made of magnesium or a magnesium alloy, provided it is no more radio-opaque than unalloyed magnesium, as determined by the method outlined in 6.4.

6.3.1.2 Use for all alloys where magnesium is the predominant alloying constituent.

6.3.2 *Materials Group 02:*

6.3.2.1 The gauge shall be made of aluminum or an aluminum alloy, provided it is no more radio-opaque than unalloyed aluminum, as determined by the method outlined in 6.4.

6.3.2.2 Use for all alloys where aluminum is the predominant alloying constituent.

6.3.3 *Materials Group 01:*

6.3.3.1 The gauge shall be made of titanium or a titanium alloy, provided it is no more radio-opaque than unalloyed titanium, as determined by the method outlined in 6.4.

6.3.3.2 Use for all alloys where titanium is the predominant alloying constituent.

6.3.4 *Materials Group 1:*

6.3.4.1 The gauge shall be made of carbon steel or Type 300 series stainless steel.

6.3.4.2 Use for all carbon steel, low-alloy steels, stainless steels, and magnesium-nickel-aluminum bronze (Superston).

6.3.5 *Materials Group 2:*

6.3.5.1 The gauge shall be made of aluminum bronze (Alloy No. 623 of Specification B150/B150M) or equivalent or nickel-aluminum bronze (Alloy No. 630 of Specification B150/B150M) or equivalent.

6.3.5.2 Use for all aluminum bronzes and all nickel aluminum bronzes.

6.3.6 *Materials Group 3:*

6.3.6.1 The gauge shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). See Specification B166.

6.3.6.2 Use for nickel-chromium-iron alloy and 18 % nickel-maraging steel.

6.3.7 *Materials Group 4:*

6.3.7.1 The gauge shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B164) or equivalent, or 70 to 30 copper-nickel alloy, (Alloy G of Specification B161) or equivalent.

6.3.7.2 Use for nickel, copper, all nickel-copper series or copper-nickel series of alloys and all brasses (copper-zinc alloys) and all leaded brasses.

6.3.8 *Materials Group 5:*

6.3.8.1 The gauge shall be made of tin-bronze (Alloy D of Specification B139/B139M).

6.3.8.2 Use for tin bronzes including gun-metal and valve bronze and leaded-tin bronzes.

6.4 Where the material to be examined is a composite, ceramic, or other non-metallic material, or for some reason cannot be obtained to fabricate a gauge, an equivalent material may be utilized, provided it is no more radio-opaque than the examination object under comparable penetrating radiation energy conditions. To determine the suitability of a substitute material, radiograph identical thicknesses of both materials on one film using the lowest penetrating radiation energy to be used in the actual examination. Transmission densitometer readings for both materials shall be in the range from 2.0 to 4.0. If the radiographic density of the substitute material is within + 15 % to − 0 % of the examination material, the substitute material is acceptable.

6.4.1 All contrast sensitivity gauges shall be suitably marked by vibro-engraving or etching. The gauge thickness and material type shall be clearly marked.

7. Imaging System Performance Levels

7.1 Imaging system performance levels are designated by a two-part measurement expressed as C(%) − U(mm). The first part of the expression C(%) refers to the depth of the shallowest flat-bottom hole that can be reliably and repeatably imaged. The second part of the expression refers to the companion spatial resolution measurement made with a resolution gauge expressed in terms of millimeters unsharpness. Where contrast sensitivity is measured for both thin and thick section performance, the performance level is expressed as C_{min}(%)–C_{max}(%)–U (mm) (see Practice E1255).

7.2 Each contrast sensitivity gauge has four flat-bottom recesses that represent 1 %, 2 %, 3 %, and 4 % of the gauge total thickness. The shallowest recess that can be repeatably and reliably imaged shall determine the limiting contrast sensitivity.

7.3 Contrast sensitivity measurements shall be made under conditions as nearly identical to the actual examination as possible. Penetrating radiation energy, image formation, processing, analysis, display, and viewing variables shall accurately simulate the actual examination environment.

8. Contrast Sensitivity Gauge Measurement Steps (see Table 1)

8.1 The gauge thickness *T* shall be within ±5 % of the examination object thickness value at which contrast sensitivity is being determined.

8.2 The gauge thickness tolerance shall be within ± 1 % of the gauge design thickness *T* or 0.001 in. (0.025 mm), whichever is greater.

8.3 The gauge recess depth tolerance shall be within ± 10 % of the design value for the shallowest recess or 0.001 in. (0.025 mm), whichever is greater.

8.4 The gauge recess inside and outside corner radius shall not exceed 0.062 in. (1.57 mm). To facilitate fabrication, the gauge may be assembled from three individually machined components: (*1*) the machined center section containing the 1 % *T*, 2 % *T*, 3 % *T*, and 4 % *T* milled slots; (*2*) the front rail, and (*3*) the rear rail. The assemblage of the three components forms the complete gauge similar to that shown in Appendix X1.

8.5 The gauge dimensional tolerances shall be held to within ± 0.010 in. (0.25 mm) of the dimensions specified in Table 2.

9. Acceptable Performance Levels

9.1 Nothing in this practice implies a mandatory or an acceptable contrast sensitivity performance level. That determination is to be agreed upon between the supplier and user of penetrating radiation examination services.

9.2 The recess depths specified in Table 1 provide measurement points at 1 %, 2 %, 3 %, and 4 % that will accommodate many imaging system configurations. Other contrast sensitivity measurement points may be obtained by placing the gauge on a shim made of the gauge material. The resulting contrast sensitivity measurement expressed as a percentage is given by the following formula:

$$\% \text{ Contrast} = \frac{R}{T+S} \times 100 \quad (1)$$

where:

R = recess depth,
S = shim thickness, and
T = gauge thickness.

If other recess depths are required to document radioscopic or radiographic system performance, special contrast sensitivity gauges may be fabricated by changing the recess depths specified in Table 1 to suit the need.

10. Performance Measurement Records

10.1 The results of the contrast sensitivity measurement should be recorded and maintained as a part of the initial qualification and performance monitoring records for the imaging system. Changes in contrast sensitivity can be an early indicator of deteriorating imaging system performance.

11. Precision and Bias

11.1 No statement is made about the precision or bias for indicating the contrast sensitivity of a radiologic (radiographic or radioscopic) system using the contrast sensitivity gauge described by this practice.

12. Keywords

12.1 contrast sensitivity gauge; gamma ray; image formation; image processing; image quality indicator; line-pairs per millimeter; penetrating radiation; spatial resolution; X-ray

APPENDIX

(Nonmandatory Information)

X1. ASSEMBLING THE CONTRAST SENSITIVITY GAUGE

X1.1 Suggested method of assembling the contrast sensitivity gauge from a milled center section with front and rear rails attached to form the complete contrast sensitivity gauge. The example shown (see Fig. X1.1) is for use with a 0.500-in. (12.7-mm) thick examination object.

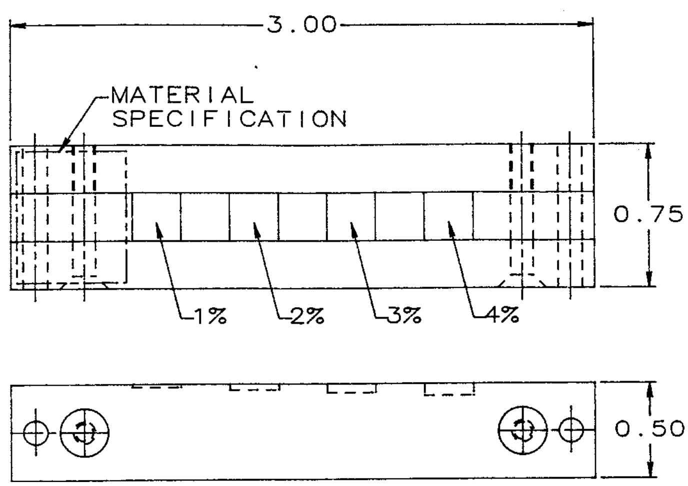

FIG. X1.1 Contrast Sensitivity Gauge

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STANDARD PRACTICE FOR MANUFACTURING CHARACTERIZATION OF DIGITAL DETECTOR ARRAYS

(19) SE-2597/SE-2597M

(Identical with ASTM Specification E2597/E2597M-14.)

Standard Practice for Manufacturing Characterization of Digital Detector Arrays

1. Scope

1.1 This practice describes the evaluation of Digital Detector Arrays (DDAs), and assures that one common standard exists for quantitative comparison of DDAs so that an appropriate DDA is selected to meet NDT requirements.

1.2 This practice is intended for use by manufacturers or integrators of DDAs to provide quantitative results of DDA characteristics for NDT user or purchaser consumption. Some of these tests require specialized test phantoms to assure consistency among results among suppliers or manufacturers. These tests are not intended for users to complete, nor are they intended for long term stability tracking and lifetime measurements. However, they may be used for this purpose, if so desired.

1.3 The results reported based on this standard should be based on a group of at least three individual detectors for a particular model number.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E1316 Terminology for Nondestructive Examinations

E1815 Test Method for Classification of Film Systems for Industrial Radiography

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2445 Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems

E2446 Practice for Classification of Computed Radiology Systems

2.2 *Other Standards:*

ISO 7004 Photography—Industrial Radiographic Films—Determination of ISO Speed, ISO Average Gradient and ISO Gradients G2 and G4 When Exposed to X- and Gamma-Radiation

IEC 62220-1 Medical Electrical Equipment Characteristics of Digital X-ray Imaging Devices Part 1: Determination of the Detective Quantum Efficiency

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *achievable contrast sensitivity (CSa)*—optimum contrast sensitivity (see Terminology E1316 for a definition of contrast sensitivity) obtainable using a standard phantom with an X-ray technique that has little contribution from scatter.

3.1.2 *active DDA area*—the size and location of the DDA, which is recommended by the manufacturer as usable.

3.1.3 *bad pixel*—a pixel identified with a performance outside of the specification range for a pixel of a DDA as defined in 6.2.

3.1.4 *burn-in*—change in gain of the scintillator that persists well beyond the exposure.

3.1.5 *calibration*—correction applied for the offset signal, and the non-uniformity of response of any or all of the X-ray beam, scintillator and the read-out structure.

3.1.6 *contrast-to-noise ratio (CNR)*—quotient of the difference of the mean signal levels between two image areas and the standard deviation of the signal levels. As applied here, the two image areas are the step-wedge groove and base material. The standard deviation of the intensity of the base material is a measure of the noise. The CNR depends on the radiation dose and the DDA system properties.

3.1.7 *detector signal-to-noise ratio–normalized (dSNRn)*—the SNR is normalized for basic spatial resolution SRb as measured directly on the detector without any object other than beam filters in the beam path.

3.1.8 *digital detector array (DDA) system*—an electronic device that converts ionizing or penetrating radiation into a discrete array of analog signals which are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted upon the input region of the device. The conversion of the ionizing or penetrating radiation into an electronic signal may transpire by first converting the ionizing or penetrating radiation into visible light through the use of a scintillating material. These devices can range in speed from many seconds per image to many images per second, up to and in excess of real-time radioscopy rates (usually 30 frames per seconds).

3.1.9 *DDA gain image*—image obtained with no structured object in the X-ray beam to calibrate pixel response in a DDA.

3.1.10 *DDA offset image*—image of the DDA in the absence of X-rays providing the background signal of all pixels.

3.1.11 *efficiency—dSNRn* (see 3.1.7) divided by the square root of the dose (in mGy) and is used to measure the response of the detector at different beam energies and qualities.

3.1.12 *frame rate*—number of frames acquired per second.

3.1.13 *GlobalLag1f (global lag 1st frame)*—the ratio of mean signal value of the first frame of the DDA where the X-rays are completely off to the mean signal value of an image where the X-rays are fully on. This parameter is specifically for the integration time used during data acquisition.

3.1.14 *GlobalLag1s (global lag 1 s)*—the projected value of GlobalLag1f for an integration time of 1 se.

3.1.15 *GlobalLag60s (global lag 60 s)*—the ratio between mean gray value of an image acquired with the DDA after 60 s where the X-rays are completely off, to same of an image where the X-rays are fully on.

3.1.16 *gray value*—the numeric value of a pixel in a DDA image. This is typically interchangeable with the terms *pixel value, detector response, Analog-to-Digital Unit,* and *detector signal*.

3.1.17 *internal scatter radiation (ISR)*—scattered radiation within the detector.

3.1.18 $iSRb^{detector}$—the interpolated basic spatial resolution of the detector indicates the smallest geometric detail, which can be resolved spatially using a digital detector array with no geometric magnification.

NOTE 1—It is equal to 1⁄2 of the measured detector unsharpness and it is determined from a digital image of the duplex wire IQI (Practice E2002), directly placed on the DDA without object. The $iSRb^{detector}$ value is determined from the interpolated or approximated modulation depth of two, or several, neighbor wire pairs at 20 % modulation depth.

3.1.19 *lag*—residual signal in the DDA that occurs shortly after the exposure is completed.

3.1.20 *phantom*—a part or item being used to quantify DDA characterization metrics.

3.1.21 *pixel value*—the numeric value of a pixel in a DDA image. This is typically interchangeable with the term *gray value*.

3.1.22 *saturation gray value*—the maximum possible gray value of the DDA after offset correction.

3.1.23 *signal-to-noise ratio (SNR)*—quotient of mean value of the intensity (signal) and standard deviation of the intensity (noise). The SNR depends on the radiation dose and the DDA system properties.

3.1.24 *specific material thickness range (SMTR)*—the material thickness range within which a given image quality is achieved. As applied here, the wall thickness range of a DDA, whereby the thinner wall thickness is limited by 80 % of the maximum gray value of the DDA and the thicker wall thickness by a SNR of 130:1 for 2 % contrast sensitivity and SNR of 250:1 for 1 % contrast sensitivity. Note that SNR values of 130:1 and 250:1 do not guarantee that 2 % and 1 % contrast sensitivity values will be achieved, but are being used to designate a moderate quality image, and a higher quality image respectively.

3.1.25 *step-wedge*—a stepped block of a single metallic alloy with a thickness range that is to be manufactured in accordance with 5.2.

4. Significance and Use

4.1 This practice provides a means to compare DDAs on a common set of technical measurements, realizing that in practice, adjustments can be made to achieve similar results even with disparate DDAs, given geometric magnification, or other industrial radiologic settings that may compensate for one shortcoming of a device.

4.2 A user must understand the definitions and corresponding performance parameters used in this practice in order to make an informed decision on how a given DDA can be used in the target application.

4.3 The factors that will be evaluated for each DDA are: interpolated basic spatial resolution ($iSR_b^{detector}$), efficiency (Detector *SNR*-normalized (*dSNRn*) at 1 mGy, for different energies and beam qualities), achievable contrast sensitivity (*CSa*), specific material thickness range (*SMTR*), image lag, burn-in, bad pixels and internal scatter radiation (*ISR*).

5. Apparatus

5.1 *Duplex Wire Image Quality Indicator for* $iSRb^{detector}$—The duplex wire quality indicator corresponds to the design specified in Practice E2002 for the measurement of $iSRb^{detector}$ and not unsharpness.

5.2 *Step-Wedge Image Quality Indicator*—The wedge has six steps in accordance with the drawing provided in Fig. 1. The wedge may be formed with built-in masking to avoid X-ray scatter and undercut. In lieu of built-in masking, the step-wedge may be inserted into a lead frame. The lead frame can then extend another 25.4 mm [1 in.] about the perimeter of the step-wedge, beyond the support. The slight overlap of the

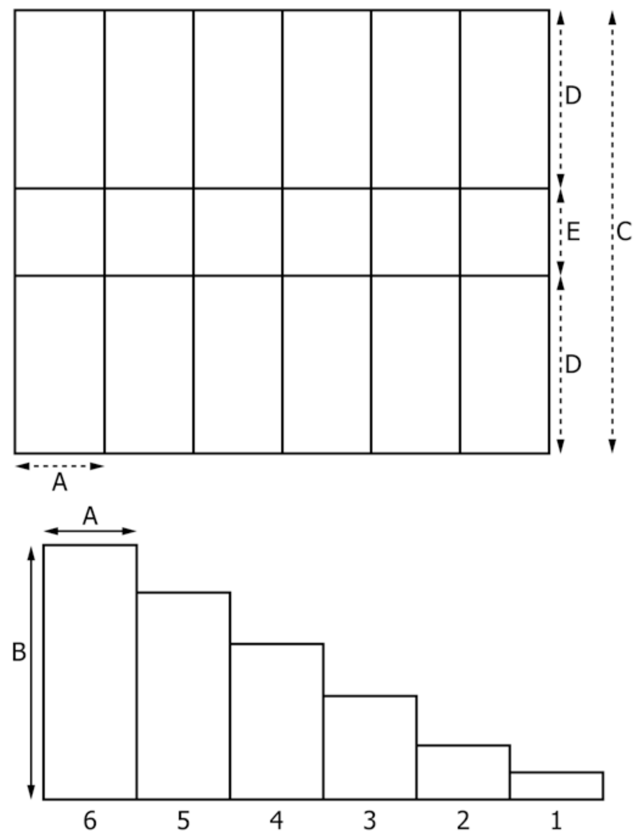


FIG. 1 Step-Wedge Drawing (dimensions are listed in Table 1)

lead support with the edges of the step-wedge (no more than 6 mm [~0.25 in.] assures a significantly reduced number of X-rays to leak-through under the step-wedge that will contaminate the data acquired on each step. The step-wedges shall be formed of three different materials: Aluminum 6061, Titanium Ti-6Al-4V, and Inconel 718 with a center groove in each step, as shown in Fig. 1. The dimensions of the wedges for the different materials are shown in Table 1.

5.3 *Filters for Measuring Efficiency of the DDA*—The following filter thicknesses (5.3.1 – 5.3.7) and alloys (5.3.8) shall be used to obtain different radiation beam qualities and are to be placed at the output of the beam. The tolerance for these thicknesses shall be ±0.1 mm [±0.004 in.].

5.3.1 No external filter (50 kV).

5.3.2 30 mm [1.2 in.] aluminum (90 kV).

5.3.3 40 mm [1.6 in.] aluminum (120 kV).

5.3.4 3 mm [0.12 in.] copper (120 kV).

5.3.5 10 mm [0.4 in.] iron (160 kV).

5.3.6 8 mm [0.3 in.] copper (220 kV).

5.3.7 16 mm [0.6 in.] copper (420 kV].

5.3.8 The filters shall be placed directly at the tube window. The aluminum filter shall be composed of aAluminum 6061. The copper shall be composed of 99.9 % purity or better. The iron filter shall be composed of Stainless Steel 304.

NOTE 2—Radiation qualities in 5.3.2 and 5.3.3 are in accordance with DQE standard IEC62220-1, and radiation quality in 5.3.4 and 5.3.5 are in accordance with ISO 7004. Radiation quality in 5.3.6 is used also in Test Method E1815, Practice E2445, and Practice E2446.

5.4 *Filters for Measuring, Burn-In and Internal Scatter Radiation*—The filters for measuring burn-in and ISR shall consist of a minimum 16 mm [0.6 in.] thick copper plate (5.3.7) 100 by 75 mm [4 by 3 in.] with a minimum of one sharp edge. If the DDA is smaller than 15 by 15 cm [5.9 by 5.9 in.] use a plate that is dimensionally 25 % of the active DDA area.

6. Calibration and Bad Pixel Standardization

6.1 *DDA Calibration Method*—Prior to qualification testing the DDA shall be calibrated for offset, or gain, or both, (see 3.1.10 and 3.1.9) to generate corrected images per manufacturer's recommendation. It is important that the calibration procedure be completed as would be done in practice during routine calibration procedures. This is to assure that data collected by manufacturers will closely match that collected when the system is entered into service.

6.2 *Bad Pixel Standardization for DDAs*—Manufacturers typically have different methods for correcting bad pixels. Images collected for qualification testing shall be corrected for bad pixels as per manufacturer's bad pixel correction procedure wherever required. In this section a standardized nomenclature is presented. The following definitions enable classification of pixels in a DDA as bad or good types. The manufacturers are to use these definitions on a statistical set of detectors in a given detector type to arrive at "typical" results for bad pixels for that model. The identification and correction of bad pixels in a delivered DDA remains in the purview of agreement between the purchaser and the supplier.

6.2.1 *Definition and Test of Bad Pixels:*

6.2.1.1 *Dead Pixel*—Pixels that have no response, or that give a constant response independent of radiation dose on the detector.

6.2.1.2 *Over Responding Pixel*—Pixels whose gray values are greater than 1.3 times the median gray value of an area of a minimum of 21×21 pixels. This test is done on an offset corrected image.

6.2.1.3 *Under Responding Pixel*—Pixels whose gray values are less than 0.6 times the median gray value of an area of a minimum of 21×21 pixels. This test is done on an offset corrected image.

6.2.1.4 *Noisy Pixel*—Pixels whose standard deviation in a sequence of 30 to 100 images without radiation is more than six times the median pixel standard deviation for the complete DDA.

6.2.1.5 *Non-Uniform Pixel*—Pixel whose value exceeds a deviation of more than ±1 % of the median value of its 9×9 neighbor pixel. The test should be performed on an image where the average gray value is at or above 75 % of the DDA's linear range. This test is done on an offset and gain corrected image.

6.2.1.6 *Persistence/Lag Pixel*—Pixel whose value exceeds a deviation of more than a factor of two of the median value of its 9×9 neighbors in the first image after X-ray shut down and are exceeds six times the median noise value in the dark image (refer to 7.11.1).

TABLE 1 Dimension of the Three Step-Wedges for Three Different Materials Used as Image Quality Indicators in this Practice

Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Inconel 718)	mm	35.0	1.25	2.5	5.0	7.5	10.0	12.5	175.0	70.0	35.0
Tolerance (±)	microns	200	25	25	38	38	38	38	200	200	200
5 % Groove	microns		63	125	250	375	500	625			
Tolerance (±)	microns		10	10	10	10	10	10			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Ti-6Al-4V)	mm	35.0	2.5	5.0	7.5	10.0	20.0	30.0	175.0	70.0	35.0
Tolerance (±)	microns	200	50	50	50	50	50	50	200	200	200
5 % Groove	microns		125	250	375	500	1000	1500			
Tolerance (±)	microns		10	10	10	10	10	10			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Al-6061)	mm	35.0	10.0	20.0	40.0	60.0	80.0	100.0	175.0	70.0	35.0
Tolerance (±)	microns	200	100	100	300	300	300	300	200	200	200
5 % Groove	microns		500	1000	2000	3000	4000	5000			
Tolerance (±)	microns		13	25	50	50	50	50			
The values stated in SI units above and inch-pound units below are to be regarded separately as standard.											
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Inconel 718)	inch	1.4	0.05	0.1	0.2	0.3	0.4	0.5	6.9	2.8	1.4
Tolerance (±)	mils	8.0	1.0	1.0	1.5	1.5	1.5	1.5	8.0	8.0	8.0
5 % Groove	mils		2.5	4.9	9.8	14.8	19.7	24.6			
Tolerance (±)	mils		0.5	0.5	0.5	0.5	0.5	0.5			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Ti-6Al-4V)	inch	1.4	0.1	0.2	0.3	0.4	0.8	1.2	6.9	2.8	1.4
Tolerance (±)	mils	8.0	2.0	2.0	2.0	2.0	2.0	2.0	8.0	8.0	8.0
5 % Groove	mils		4.9	9.8	14.8	19.7	39.4	59.1			
Tolerance (±)	mils		0.5	0.5	0.5	0.5	0.5	0.5			
Material	Unit	A	B1	B2	B3	B4	B5	B6	C	D	E
Step-wedge (Al-6061)	inch	1.4	0.4	0.8	1.6	2.4	3.1	3.9	6.9	2.8	1.4
Tolerance (±)	mils	8.0	4.0	4.0	12.0	12.0	12.0	12.0	8.0	8.0	8.0
5 % Groove	mils		19.7	39.4	78.7	118.1	157.5	196.9			
Tolerance (±)	mils		0.5	1.0	2.0	2.0	2.0	2.0			

6.2.1.7 *Bad Neighborhood Pixel*—Pixel, where all eight neighboring pixels are bad pixels, is also considered a bad pixel.

6.2.2 *Types or Groups of Bad Pixels:*

6.2.2.1 *Single Bad Pixel*—A single bad pixel is a bad pixel with only good neighborhood pixels.

6.2.2.2 *Cluster of Bad Pixels*—Two or more connected bad pixels are called a cluster. Pixels are called connected if they are connected by a side or a corner (eight-neighborhood possibilities). Pixels which do not have five or more good neighborhood pixels are called cluster kernel pixel (CKP) (Fig. 2).

6.2.2.3 A cluster without any CKP is well correctable and is labeled an irrelevant cluster. The name of the cluster is the size of a rectangle around the cluster and number of bad pixels in the irrelevant cluster, for example, "2×3 cluster4" (Fig. 2).

6.2.2.4 A cluster (excluding a bad line segment defined in 6.2.2.5) with CKP is labeled a relevant cluster. A line cluster with CKP is classified differently (example given below and demonstrated in Fig. 2). The name of the cluster is similar to the irrelevant cluster; with the exception that the prefix "rel" is added and the number of CKPs is provided as a suffix, for example, "rel3×4 cluster7-2", where 7 is the total number of bad pixels and two are those in this group that are CKPs.

6.2.2.5 A bad line segment is a special cluster with ten or more bad pixels connected in a line (row or column) where no more than 10 % of this line has adjacent bad pixels. If there are CKPs in the line segment, then the following rule is to be followed: As shown in Fig. 2b a relevant cluster is located at the end of a bad line segment. The bad line segment is then separated from the relevant cluster. In this example, the bad line segment is a 1×51 Line51 and attached with a relevant cluster Rel4×3 cluster 8-5.

7. Procedure

7.1 Beam filtration shall be defined by the test procedure for each individual test. It is to be noted that intrinsic beam filters may be installed in the X-ray tube head. Where possible, those values should be obtained and listed.

7.2 For all measurements the X-ray source to detector distance (SDD) shall be ≥1000 mm [~ 40 in.], unless specifically mentioned. The beam shall not interact with any other interfering object other than that intended, and shall not be considerably larger than the detector area through the use of collimation at the source.

NOTE 3—The exposure times listed in this procedure can be obtained by any combination of extended exposures or multiple frames as available from the DDA. However, whichever is used, that information shall be recorded in the test report and the same DDA integration time (per frame) shall be used for all tests. In the following sections, where an image is required, this image shall be stored in a format that contains the full bit depth of the acquisition for later analysis.

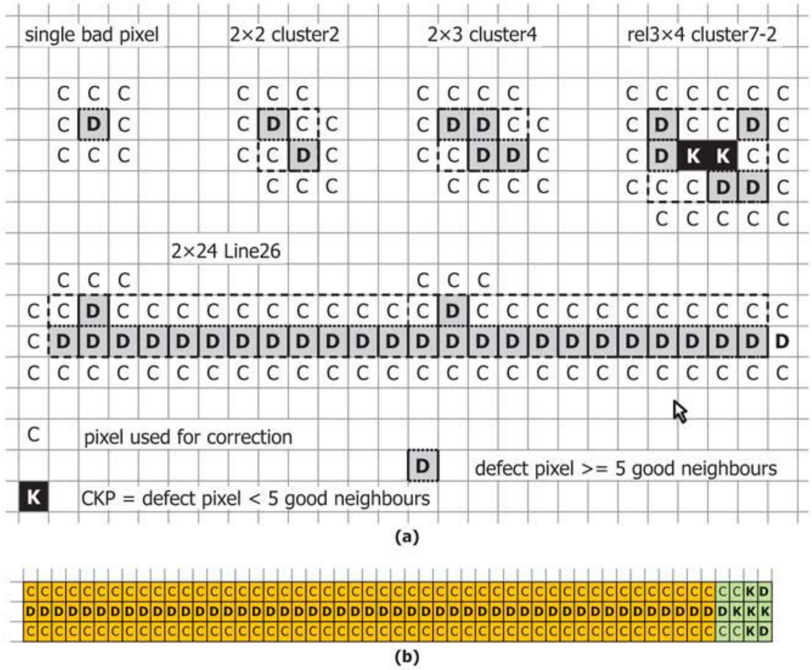


FIG. 2 (2) Different Types of Bad Pixel Groups: Cluster, Relevant Cluster, and Bad Line. (b) Example of a Bad Line Segment Separated from a Relevant Cluster at the End. The line Segment is a 1x51 Line51 and Attached to a Relevant Cluster rel 4x4 cluster 8-5.

7.3 The geometric unsharpness shall be less than or equal to 5 % of the total unsharpness for the $iSR_b^{detector}$ measurements. This avoids additional unsharpness due to the finite size of the X-ray focal spot on the measurement of $iSR_b^{detector}$. See example below.

e.g. 100 µm pixel size→focal spot size maximum 2 mm
Duplex wire to active sensor area distance : 2.5 mm
Source to Object distance : 1 000 mm
Maximum expected unsharpness : 2 mm / 1 000 mm × 2.5 mm = 0.005 mm = 5 µm
Maximum unsharpness due to the limited focal spot size in percent : 5 %

7.4 Measurement parameters for each test shall be recorded using the data-sheet template provided in Appendix X1, Data Sheet (Input).

7.5 All images shall be calibrated for offset and gain variations of the DDAs unless otherwise mentioned. Bad pixel correction using the manufacturer's correction algorithms also needs to be completed for all tests with the exclusion of the bad pixel identification testing (see 7.12 and 8.7).

7.6 All tests specified for a given DDA type need to be performed at the same internal detector settings such as gain and analog-digital conversion.

7.7 *Measurement Procedure for Interpolated Basic Spatial Resolution* ($iSR_b^{detector}$)*:*

7.7.1 The test object to measure the $iSR_b^{detector}$ is the duplex wire gage (Practice E2002). It should be placed directly on the detector with an angle between 2° and 5° to the rows/columns of the detector. If a DDA has a non-isotropic pixel, two images shall be made, one with the duplex wire near parallel to the columns and one near parallel to the rows. No image processing shall be used other than gain/offset and bad pixel corrections.

NOTE 4—For the extended quality numbers (> 15) listed in Table 2 as discussed in Section 9 there are no duplex wires defined in Practice E2002. A special gage will be needed with wire pairs smaller than 50 µm to report in this extended quality regime. Any other gages used to perform the measurement shall be documented along with the test results

7.7.2 The exposure shall be performed at a distance of ≥ 1 m [≥ 40 in.] using geometric unsharpness levels as specified in 7.3.

7.7.3 The measurement of the interpolated basic spatial resolution of the detector may depend on the radiation quality. For DDAs that can operate above 160 kV, the test shall be performed with 220 kV. A filter of up to 0.5 mm Copper in front of the tube port shall be used. For all other DDAs, the test shall be completed at 90 kV (no pre-filtering or a filter of up to 0.5 mm Copper in front of the tube port). The mA of the X-ray tube shall be selected such that the gray value of the object (the duplex wire gage) is between 50 % and 80 % of full saturation for that DDA. If this cannot be achieved, a SNR of ≥ 100 shall be obtained. Frame integration is recommended to achieve the required SNR. If the gray value of 80 % of full saturation is exceeded the source to DDA distance shall be increased until the required grey level is reached.

NOTE 5—The intent of this test is to determine the achievable $iSR_b^{detector}$ obtainable from the DDA under test. In this regard, it is important that the quantum noise of the measurement be significantly reduced. This may involve capturing multiple frames at the gray values listed above to fall within the procedure listed in 7.7.

TABLE 2 Quality Numbers for Three Different Materials

	Inconel				Quality Number																Quality Number Extended									
Parameter	Unit	High	Low	Condition	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$iSR_B^{detector}$ (basic spatial resolution)	µm	3,2	1000	220 kV no filter	1000	800	630	500	400	320	250	200	160	130	100	80	63	50	40	32	25	20	16	13	10	8	6,3	5	4	3,2
CS (contrast sensitivity)	%	0,010	3,2	In, 160 kV, 4 s, (% Σ 1.25 to 12.5 mm)/6	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Image Lag	%	0,010	3,2	1st frame, normalized to [1 s]	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Efficiency = dSNRn @ 1 mGy	–	1200	200	@ 160 kV, 10 mm Fe	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000	1040	1080	1120	1160	1200
Specific Material Thickness Range	mm	12,5	2,5	In, 160 kV, 4 s, SNR > 130	2,5	3,17	3,83	4,5	5,17	5,83	6,5	7,17	7,83	8,5	9,17	9,83	10,5	11,2	11,8	12,5	13,2	13,8	14,5	15,2	15,8	16,5	17,2	17,8	18,5	19,2

	Titanium				Quality Number																Quality Number Extended									
Parameter	Unit	High	Low	Condition	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$iSR_B^{detector}$ (basic spatial resolution)	µm	3,2	1000	220 kV no filter	1000	800	630	500	400	320	250	200	160	130	100	80	63	50	40	32	25	20	16	13	10	8	6,3	5	4	3,2
CS (contrast sensitivity)	%	0,010	3,2	Ti, 160 kV, 4 s, (% Σ 2.5 to 30 mm)/6	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Image Lag	%	0,010	3,2	1st frame, normalized to [1 s]	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Efficiency = dSNRn @ 1 mGy	–	1200	200	@ 160 kV, 10 mm In	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000	1040	1080	1120	1160	1200
Specific Material Thickness Range	mm	38	5	Ti, 160 kV, 4 s, SNR > 130	5	6,33	7,67	9	10,3	11,7	13	14,3	15,7	17	18,3	19,7	21	22,3	23,7	25	26,3	27,7	29	30	31,7	33	34,3	35,7	37	38,3

	Aluminum				Quality Number																Quality Number Extended									
Parameter	Unit	High	Low	Condition	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$iSR_B^{detector}$ (basic spatial resolution)	µm	3,2	1000	220 kV no filter	1000	800	630	500	400	320	250	200	160	130	100	80	63	50	40	32	25	20	16	13	10	8	6,3	5	4	3,2
CS (contrast sensitivity)	%	0,010	3,2	Al, 160 kV, 4 s, (% Σ 10 to 100 mm)/6	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Image Lag	%	0,010	3,2	1st frame, normalized to [1 s]	3,2	2,5	2	1,6	1,3	1	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,13	0,1	0,080	0,053	0,050	0,040	0,032	0,025	0,020	0,016	0,013	0,010
Efficiency = dSNRn @ 1 mGy	–	1500	250	@ 120 kV, 40 mm Al	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
Specific Material Thickness Range	mm	150	20	Al, 160 kV, 4 s, SNR > 130	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150

NOTE 1—For extended Quality Numbers, beyond 16 additional plates below the step wedge shall be used for measurement of Specific Material Thickness Range.
1. For Inconel measurement the thickness of the Inconel plate shall be 7.5 mm to extend the wedge for the scale by 10 quality values.
2. For Titanium measurement the thickness of the titanium plate shall be 10 mm to extend the wedge for the scale by 10 quality values.
3. For Aluminum measurement the thickness of the aluminum plate shall be 50 mm to extend the wedge for the scale by 10 quality values.
4. For SMTR measurement in the extended range the X-ray dose (mA) still shall be set that no saturation occurs on the thinnest step without the extension plate.

7.8 *Measurement Procedure for Efficiency:*

7.8.1 The measurement shall be performed at a few points where the dose is above and below 1 mGy. The efficiency at 1 mGy can then be computed from the series of measured points. The series of points measured during the tests also provides additional information on the linear response of the detector. A few data points at the top of the response of the DDA is also recommended to obtain maximum levels of *dSNRn*.

7.8.2 An offset image (without radiation) shall be collected using the same integration time as the images described in 7.8.4.

7.8.3 The radiation qualities to be used for this measurement are defined in 5.3.

7.8.4 To achieve the efficiency measurement, the X-ray tube settings shall be as those listed in 5.3, with the filters located immediately adjacent to the port of the X-ray tube, such that no unfiltered radiation is reaching the DDA. The beam current, or time of exposure, or both, shall be adjusted such that a certain known dose is obtained at the location of the DDA as measured with an ionization gage. The measurement of dose rate shall be made without any interference from scatter, so it is best to complete this measurement prior to placing the detector. The dose is obtained by multiplying the dose rate by the exposure time in seconds (or fractions thereof). To arrive at the 1 mGy dose, it is recommended to measure all of the data points (few points below and above 1 mGy dose) and record the mAs values required to achieve these dose levels prior to placing the detector.

NOTE 6—The ionization gage used for measuring the dose rate should be calibrated as per the recommendation by its manufacturer.

7.8.5 For each dose, two images are collected. These are used to acquire the noise without fixed patterns or other potential anomalies through a difference image.

7.9 *Measurement Procedure for Achievable Contrast Sensitivity:*

7.9.1 The step-wedge image quality indicators of three different materials shall be used for this test, as defined in 5.2. The full range of thickness of these shall be used as described in 5.2. The step-wedge shall be placed for all these tests at a minimum of 600 mm [24 in.] from the detector (while SDD is ≥1000 mm [40 in.]). The pre-filter should be placed directly in front of the tube. The beam shall be collimated to an area where only the step-wedge is exposed. The pre-filter used shall be recorded in the data sheet (input).

7.9.2 If the area of the detector is too small to capture the complete stepwedge within one image, two or more images with identical X-ray and DDA settings may be captured to cover the complete step-wedge.

7.9.3 The energy for this measurement shall be set to 160 kV, with a 0.5 mm [0.02 in.] copper filter. If the DDA is not specified to such high energy, the maximum allowed energy shall be used; in that case the energy used shall be printed in the data sheet (output) "C" and "D" (see appendix X1.2 for details). The X-ray tube current (mA) under this beam spectrum shall be determined such that the DDA is not saturated under the thinnest step for the integration time selected for all tests. Images shall be generated by averaging frames to obtain as minimum 1 s, 4 s, 16 s, and 64 s effective exposure times. The manufacturer can provide data at other exposure times if required.

7.10 *Measurement Procedure for Specific Material Thickness Range:*

7.10.1 No further measurements are needed for this test, if the procedure in 7.9 was already completed. If this test needs to be completed independent of the CS test, then the procedure in 7.9 shall be followed. If this test shall be performed with the extended quality level (larger than 15), the procedure in 7.9 shall be followed with the additional plate specified in Table 2; the X-ray and DDA settings shall be the same as specified in 7.9.3; the X-ray tube current (mA) under this beam spectrum shall be determined such that the DDA is not saturated under the thinnest step without the additional plate for the integration time selected for all tests.

7.11 *Measurement Procedure of Lag and Burn-In:*

7.11.1 *Procedure for Lag*—For this measurement, no additional gain or bad pixel correction shall be applied in the final computation.

7.11.1.1 The lag of the detector shall be measured using a sequence of images. The DDA shall be powered ON and not exposed for a suitable time to warm up the detector and remove prior lag before the measurement is acquired. An offset frame (image0) shall be captured (without radiation).

7.11.1.2 The DDA shall be exposed with a constant dose rate using a 120 kV beam with a 0.5-mm [0.020-in.] copper filter to 80 % of saturation gray value for a minimum of 5 min. Immediately following this, imagery shall be captured leading to a single image for a total exposure time of 4 s.

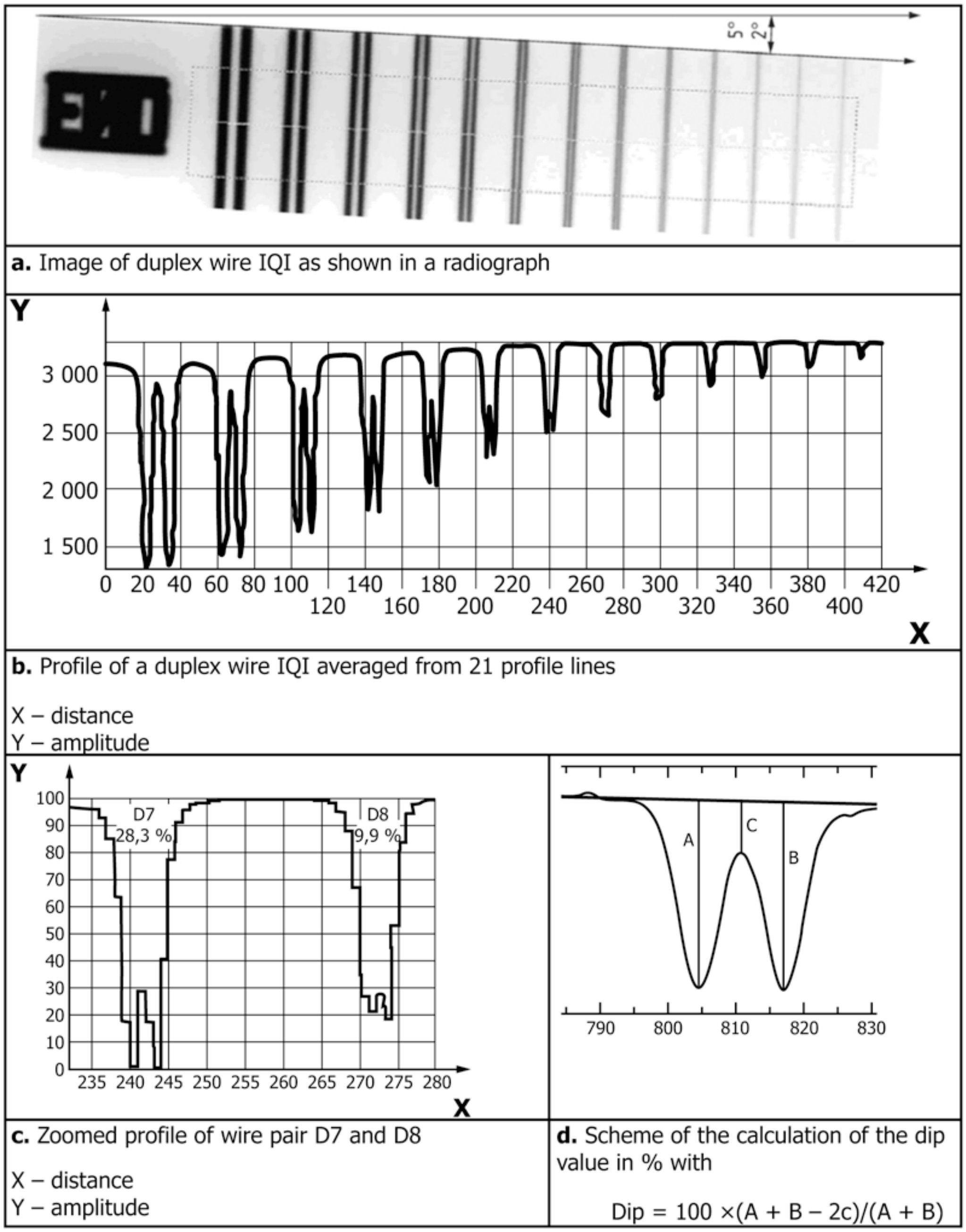
7.11.1.3 A sequence of images shall then be captured for about 70 s while shutting down the X-rays after approximately 5 s.

7.11.2 *Procedure for Burn-In:*

7.11.2.1 For this measurement offset, gain, and bad pixel corrections shall be applied to the final image that will be used for the burn-in computation. Burn-in shall be measured at 120 kV with a 16 mm copper plate directly on the surface of the DDA and covering one half of the DDA. The DDA shall be exposed for 5 min with 80 % of saturation gray value of the DDA in the area not covered by the copper plate. The X-rays shall be switched off and the copper plate shall be removed from the beam. The DDA shall be exposed at the same kV but at a tenth of the original exposure dose. An image with 30 s effective exposure time shall be captured. A shadow in the area where the copper plate was previously located may be slightly visible.

7.11.2.2 The time between the 5 min dosing and the 30 s exposure should be no longer than required to remove the copper plate from the beam. Any delay in this procedure will alter the results of the measurement. Repeat the measurement after 1 h, 4 h, and 24 h without further exposure between measurements.

7.12 *Measurement Procedure of Bad Pixel*—Data required to determine bad pixel identification are described below. All measurements shall use 100 kV with 0.5 mm [0.02 in.] copper



a. Image of duplex wire IQI as shown in a radiograph

b. Profile of a duplex wire IQI averaged from 21 profile lines

X – distance
Y – amplitude

c. Zoomed profile of wire pair D7 and D8

X – distance
Y – amplitude

d. Scheme of the calculation of the dip value in % with

Dip = 100 ×(A + B – 2c)/(A + B)

NOTE 1—Schematic of the measurement is shown at lower right.

FIG. 3 Wire-Pair Image Analysis for Calculation of Interpolated Basic Spatial Resolution of the detector ($iSR_b^{detector}$).

pre-filtering. Bad pixel tests are to be reported based on a group of at least three individual detectors for a particular model of DDA.

7.12.1 A sequence of dark images with about 120 s of total integration time for the sequence in the absence of X-ray radiation is acquired. The image sequence is stored for noisy pixels identification. The image sequence is then averaged to obtain one single offset image. This is referred to as *offsetdata*.

7.12.2 A sequence of images with about 120 s of total integration time for the image sequence is acquired using an X-ray setting where the average gray value is 50 % of the saturation gray value of the DDA range after offset correction. The image sequence is then averaged and offset corrected to obtain one single image. This is referred to as *badpixdata1*.

7.12.3 A sequence of images with about 120 s of total integration time for the image sequence is acquired using an X-ray setting such that the average gray value is 10 % of the saturation gray value of the DDA range after offset correction. These images are then averaged and offset and gain corrected. This is then referred to as *badpixdata2*.

7.12.4 A sequence of images with about 120 s total integration time is acquired using an X-ray setting such that the average gray value is 80 % of the saturation gray value of the DDA range after offset correction. These images are then averaged and offset and gain corrected. This will be referred to as *badpixdata3*.

7.12.5 *Persistence/Lag Pixel*—No gain correction shall be applied. The detector shall be powered ON and not exposed for a suitable time to warm up the detector and get rid of old lag. Before starting the exposure an offset image shall be acquired. The detector is then exposed with a constant dose rate at 120 kV using a 0.5-mm copper filter (as in 5.4) and 80 % of saturation gray value after offset correction for a minimum of 300 s. A sequence of images of about 70 s shall be captured. X-rays shall be shut off 5 s after start of the sequence.

7.13 *Measurement Procedure for Internal Scatter Radiation*—A 16-mm copper plate in accordance with 7.11 shall be placed directly on the DDA in a manner that the sharp edge is exactly in the middle of the DDA and perpendicular to the beam to get a sharp edge in the image. The DDA shall be exposed with 220 kV filtered with an 8-mm [0.31-in.] copper pre-filter. For DDAs which are not recommended for energy in this range, the test shall be performed at the highest recommended X-ray energy range with a filter between 3 mm and 8 mm of copper. The beam current of the tube shall be adjusted so that 80 % of the saturation gray value is attained after offset correction. An image shall be captured with 60 s effective exposure time using a focal spot size as specified in 7.3. The image shall be offset and gain corrected.

8. Calculation and Interpretation of Results

8.1 All test results are to be documented using the data sheet format as shown in Appendix X1, Data Sheet (Output).

8.2 *Calculation of Interpolated Basic Spatial Resolution of a DDA ($iSR_b^{detector}$):*

8.2.1 The measurement shall be done across the middle area of the IQI image integrating along the width of 60 % of the lines of the duplex wires to avoid variability along the length of the wires (Fig. 3a). A next neighbor interpolation for the line profile calculation may be used. The line defining the 100 % dip shall be calculated as the piecewise interpolation between the maximum gray values between the wire pairs (see Fig. 3 b-d).

8.2.2 For improved accuracy in the measurement of the $iSR_b^{detector}$ value the 20 % modulation depth (dip) value shall be approximated from the modulation depth (dip) values of the neighbor duplex wire modulations. Fig. 4a and Fig. 4b visualize the corresponding procedure for a high resolution system.

8.2.3 The $\mathrm{iSR_b}^{\mathrm{detector}}$ is calculated as the second order polynomial approximation of the modulation depth (dip) versus the wire pair spacing of neighbored wire pairs with at least two wire pairs with more than 20 % dip between the wires in the profile, and at least two wire pairs with less than 20 % dip between the wires in the profile (Fig. 4), if their values are larger than zero. If no values are available with dip less than 20%, one the next wire pair value with the dip of zero shall be used. If the measured $iSR_b^{detector}$ is smaller than the pixel size, e.g. due to aliasing effects, $iSR_b^{detector}$ shall be qualified as $iSR_b^{detector}$ = pixel size.

8.2.4 The calculation of the modulation depth (dip) shall be performed as shown in Fig. 4b. The resulting approximated or interpolated basic spatial resolution value shall be documented as "interpolated SRb detector-value" or iSRb detector.

NOTE 7—The dependence of modulation depth (dip) from wire pair spacing shall be fitted with a polynomial function of second order for calculation of the intersection with the 20 % line as indicated in Figure Fig. 4b.

8.3 *Calculations for Efficiency:*

8.3.1 The efficiency is calculated by using the difference images, where the bad pixels are corrected using the manufacturer's methods for correcting bad pixels prior to differencing. No offset or gain correction shall be used for the difference images. The resultant of the difference images avoids all geometrical distortions and measures only behavior in time and dose. The noise (standard deviation) in a 50×50 pixel area is computed over five regions of the differenced image and is represented as σ*[difference image]*. The five areas of 50×50 pixels shall be placed on the image such that one is at the center of the image and four are at the corners with a distance to the edge of 10 % of the effective DDA range. The mean signal of the 50×50 pixel areas averaged over the same five locations in one of the non-differenced images shall be represented as *Mean GV[first image]*. *Mean OV* is the average in the same areas of an offset image (without radiation). *dSNRn* can be calculated using Eq 1 (the value is corrected by the square root of 2 since the difference of two images are used for noise calculations, and by the normalized resolution 88.6/*iSRb*). The *dSNRn* obtained for the five regions are to be averaged to obtain the final *dSNRn* value.

NOTE 8—This is a similar procedure to Practices E2445 and E2446 for *SNRn, but may produce different results.*

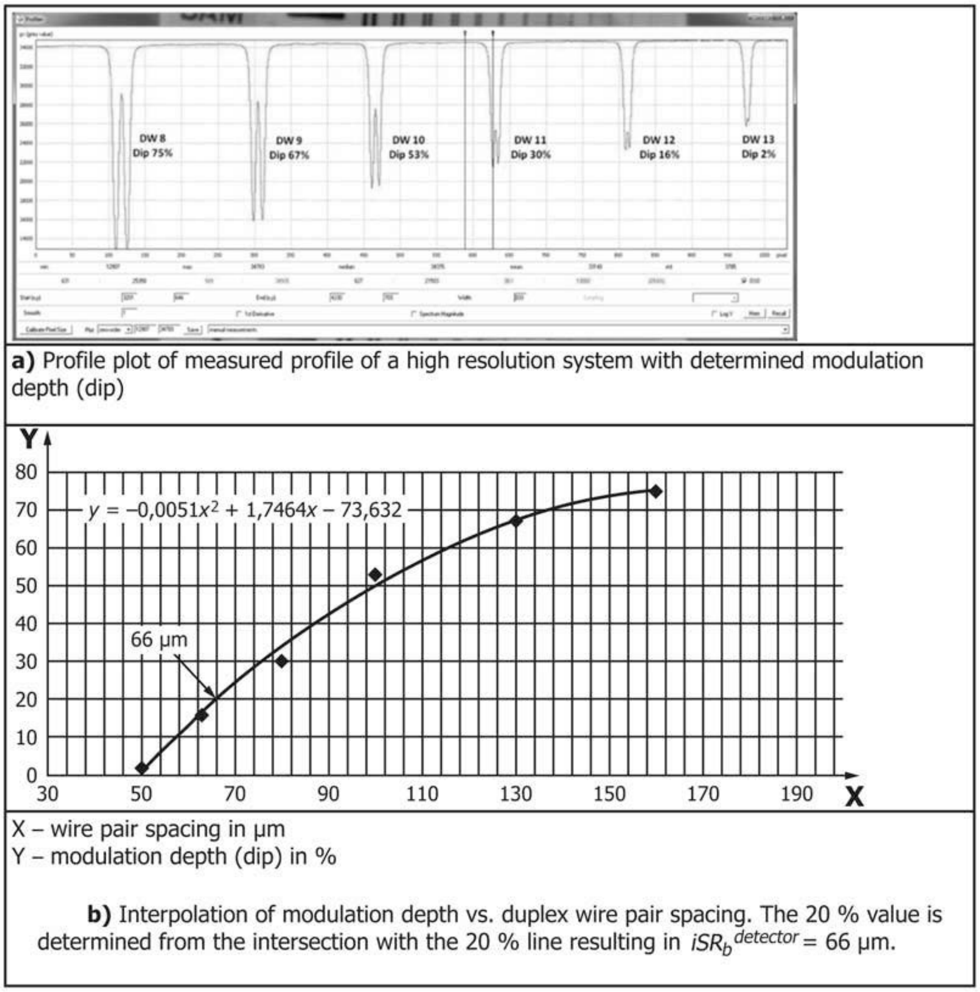
$$dSNRn = \frac{(Mean\ GV[first\ image] - Mean\ OV)}{\sigma[difference\ image]} \times \frac{(\sqrt{2} \times 88.6)}{SRb} \quad (1)$$

8.3.2 Fig. 5 provides a diagram where *dSNRn* of the difference images is shown as a function of the square root of the dose. A number of plots are shown for different radiation qualities. The slopes of the straight lines in Fig. 5 define the efficiency; it is the same value as the *dSNRn* at 1 mGy exposure level. Although measuring and computing the efficiency, as a function of dose is not required, the data may be collected and plotted at the discretion of the manufacturer. This data will provide information on the maximum *dSNRn* possible as well as information on the linear response of the detector.

8.4 *Calculations for Achievable Contrast Sensitivity (CSa):*

8.4.1 The images shall be corrected for gain, offset and bad pixels for this test.

8.4.2 The signal (mean gray value) and noise (standard deviation) on each step shall be computed in three rectangular regions as shown in Fig. 6. The minimum size of the rectangular region of interest for evaluation is 1 100 pixels (20×55 pixels). For pixel sizes larger than 250 µm each, ROI should be a minimum of 5 % of the area of the complete step of the step wedge. The noise shall be computed in the same rectangular



a) Profile plot of measured profile of a high resolution system with determined modulation depth (dip)

b) Interpolation of modulation depth vs. duplex wire pair spacing. The 20 % value is determined from the intersection with the 20 % line resulting in $iSR_b^{detector}$ = 66 µm.

FIG. 4 Wire-Pair Image Analysis for Calculation of interpolated Basic Spatial Resolution of the detector ($iSR_b^{detector}$).

region using the median of the single line standard deviations as described in Practice E2446. *CNR(5 %)* shall be computed as the ratio between contrast (difference in signal between the region on the groove and those off the groove) and noise of those regions off the groove, as shown in Eq 2. This is computed for each step of the step-wedge images.

$$CNR(5\%) = \frac{0.5 \times (signal(area\ 1) + signal(area\ 3)) - signal(area\ 2)}{0.5 \times (noise(area\ 1) + noise(area\ 3))} \quad (2)$$

8.4.3 With a groove thickness of 5 % of the base step thickness, the *CSa* can be calculated as:

$$CSa = \left[\frac{5}{CNR(5\%)}\right] \times 100\% \quad (3)$$

8.4.4 The results shall be documented as shown in the output data sheet in Appendix X1. An example plot of the achievable contrast sensitivity is shown in Fig. 7. The contrast sensitivity reported here is the best achievable contrast sensitivity as scatter from the part is greatly reduced. In practice the achievable contrast sensitivity curve may differ from these results as geometrical unsharpness and scattered radiation may be different at the user facility.

8.5 *Calculations for Specific Material Thickness Range:*

8.5.1 *SNR* shall be computed for each step as described in 8.4.1 and 8.4.2. The signal and the noise shall be calculated from both areas 1 and 3 (Fig. 6) using the mean value of both. For 2 % sensitivity applications the *SNR* should be 130 or higher.

NOTE 9—This is to be considered a convention, as not all conditions where a *SNR* of 130:1 will result in 2 % contrast sensitivity.

8.5.2 In the example in Fig. 8 the specific material thickness range for "2 % sensitivity" is from 10 mm [0.39 in.], not shown on plot, to 83.8 mm [3.3 in.] aluminum with 4 s exposure time.

8.5.3 For 1 % sensitivity applications the *SNR* should be 250 or higher. Note, this is to be considered a convention, as not all conditions where a *SNR* of 250:1 will result in 1 % contrast sensitivity.

8.5.4 In the example in Fig. 8 the specific material thickness range for "1 % sensitivity" would be 10 mm [0.39 in.], not shown on plot, to 74.6 mm [2.94 in.] at 16 s for 1 % sensitivity.

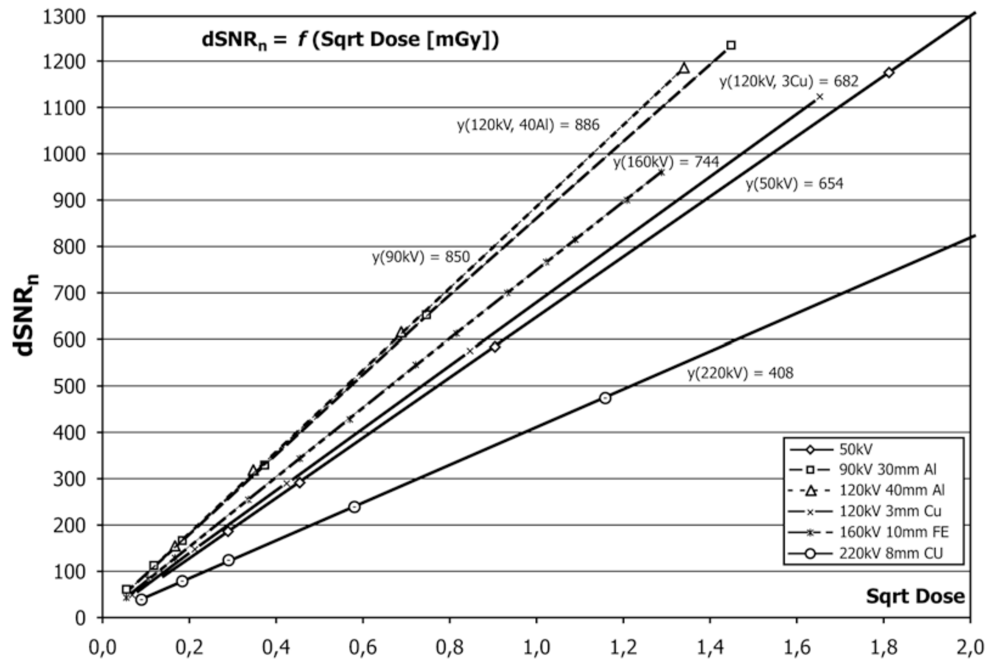


FIG. 5 Example Chart for Efficiency Test with Difference Images at Different Energy Levels

FIG. 6 Areas on the Step-Wedge Marked as Area 1, Area 2, and Area 3, which will be Used for Extracting Signal and Noise

8.6 *Calculations for Lag and Burn-In:*

8.6.1 *Lag Calculations:*

8.6.1.1 The offset image is referred as *image0*. The first image acquired for the 4 s integration time is *image1*. From the sequence of images acquired, locate the first image where it is completely dark (after shutting down X-rays), and this will be referred to as *image2*. *Image2* is the second frame after the last frame with full exposure. The image after 60 s of *image2* is to be referred to as *image3*.

8.6.1.2 In all the images the mean signal of the center 90 % of the DDA shall be measured.

GV0 = mean signal for center 90 % of *image0*.

GV1 = mean signal for center 90 % of *image1*.

GV2 = mean signal for center 90 % of *image2*.

GV3 = mean signal for center 90 % of *image3*.

8.6.1.3 The parameters GlobalLag1f, GlobalLag1s and GlobalLag60s can be calculated as shown in Eq 4. Fig. 9 shows typical lag measurement data.

$$GlobalLag2f(\%) = \frac{GV_2 - GV_0}{GV_1 - GV_0} \times 100 \quad (4)$$

$$GlobalLag1f(\%) = GlobalLag2f(\%) = \times 2$$

$$GlobalLag1s = \frac{GlobalLag1f}{framerate}$$

$$GlobalLag60s = \frac{(GV_3 - GV_0)}{(GV_1 - GV_0)} \times 100$$

8.6.2 *Calculations for Burn-in*—Burn-in shall be computed as shown in Eq 5. Fig. 10 shows typical measurement data for burn-in. *Mean GV[off the plate]* is the mean gray value outside the plate area and *Mean GV[on plate]* is the mean gray value on the plate.

$$Burn - in(time\ t)\ (\%) = \frac{Mean\ GV[off\ plate] - Mean\ GV[on\ plate]}{Mean\ GV[on\ plate]} \times 100 \quad (5)$$

8.6.2.1 Report the values for 1 min, 1 h, 4 h, and 24 h.

8.7 *Calculations for Bad Pixels*—The five categories of single bad pixels, and the three categories of cluster bad pixels are to be reported in the Output Data sheet, for which a template is provided in Appendix X1. These results are to be based on a group of at least three individual detectors for a particular model number. The methodology for computing bad pixels is included below.

8.7.1 *Dead Pixel*—Identify the number of dead pixels in each detector and take the average.

8.7.2 *Over-Responding Pixel*—Identify and document over-responding pixels from each detector in a group for a given model number using the following steps:

8.7.2.1 Test all pixels in *badpixdata1* using a 21×21 pixel mask over the image to locate pixels whose value is greater than 130 % the median gray value over the mask. Report the average number of over-responding pixels for all detectors tested.

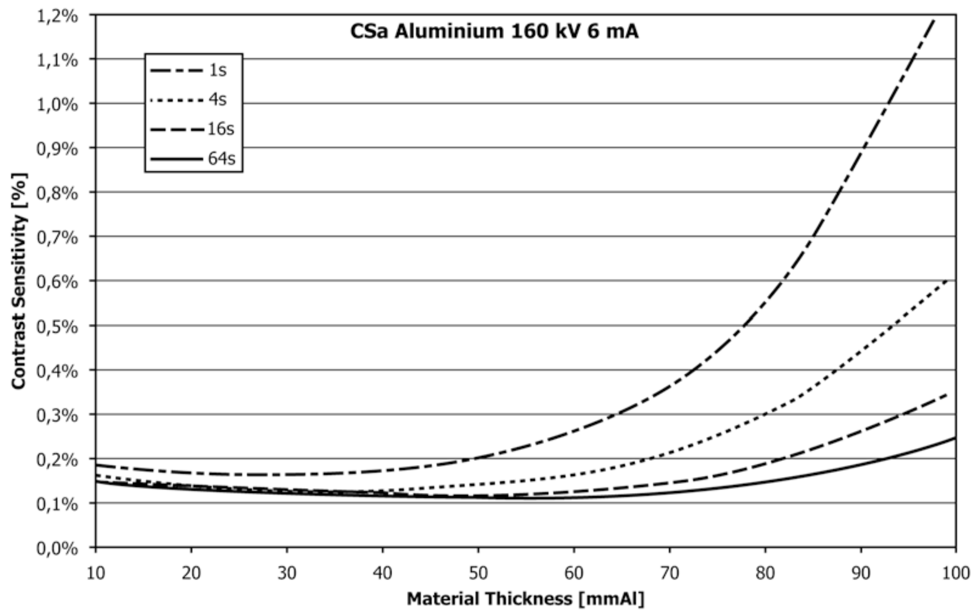


FIG. 7 Result of Achievable Contrast Sensitivity Test with Different Image Acquisition Times

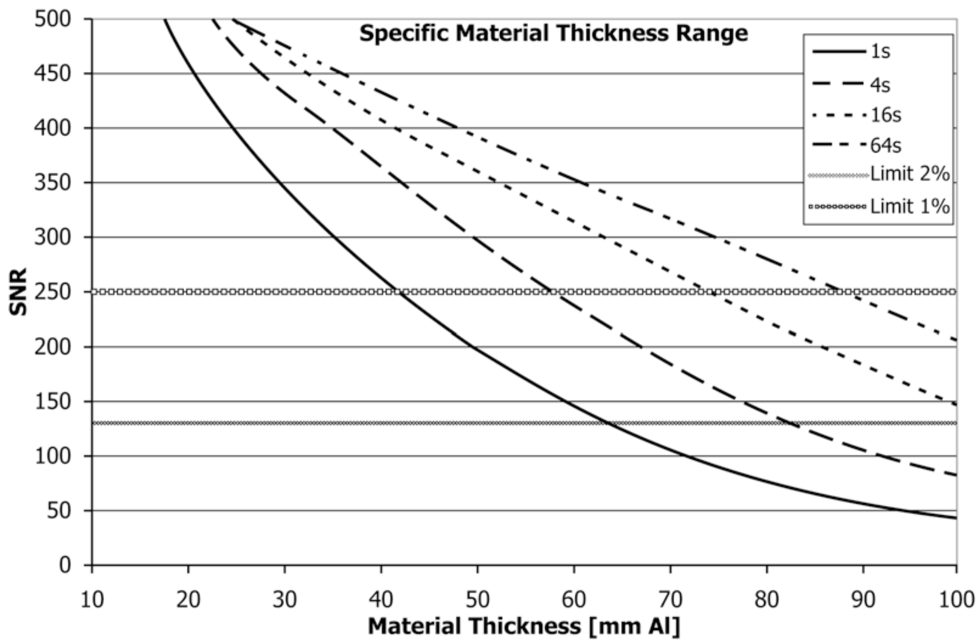


FIG. 8 Specific Material Thickness Range for 2 % Sensitivity at SNR of 130:1 (0 to 84 mm [0 to 3.3 in.] at 4 s exposure time)

8.7.3 *Under-Responding Pixel*—Identify and document under-responding pixels from each detector.

8.7.3.1 Test all pixels in *badpixdata1* using a 21×21 mask over the image to locate pixels whose value is less than 60 % the median gray value over the mask.

8.7.3.2 Report the average number of over-responding pixels for all detectors tested.

8.7.4 *Noisy Pixel*—The pixel sigma for each pixel across the dark image sequence and the median pixel sigma are calculated. This is completed for each detector under test. The average is the number to report. The following procedure may be followed to compute the number of noisy pixels.

8.7.4.1 Compute the standard deviation value at every pixel location from the image sequence to create a standard deviation image, where every pixel value is replaced with the standard deviation at that location. Compute a median of the standard deviation image over the effective DDA range (σ_m). Any pixel in the standard deviation image, whose value is greater than six times the median value σ_m is marked as a noisy pixel.

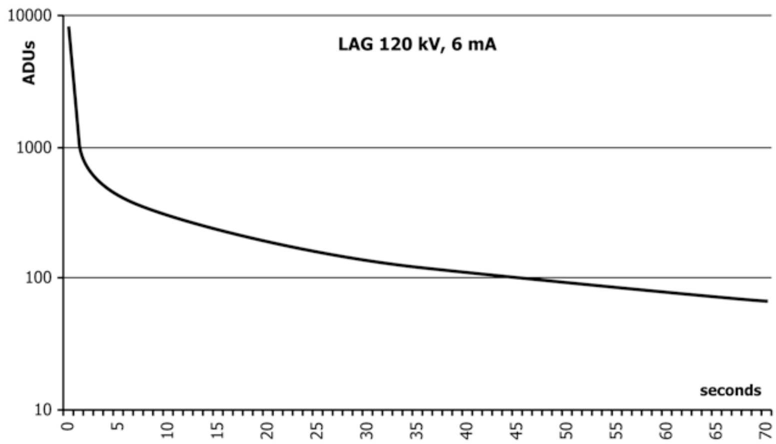


FIG. 9 Result of Image Lag Measurement Sequence

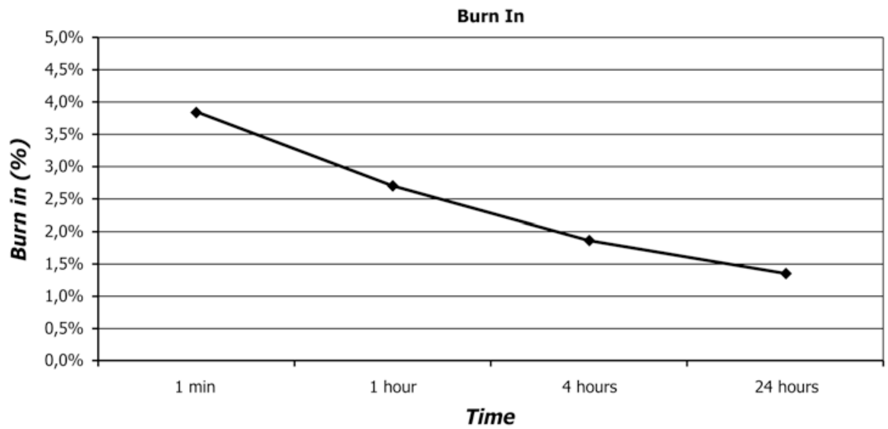


FIG. 10 Result of Burn-In Measurement

8.7.5 *Non-Uniform Pixel*—A pixel is marked as bad if after applying offset and gain correction, its value exceeds a deviation of more than ±1 % of the median value of its 9×9 neighbors. *Badpixdata2* and *Badpixdata3* shall be used for this test. The following procedure may be followed to compute the number of non-uniform pixels.

8.7.5.1 Use a mask of 9×9 pixels over the effective DDA range in *Badpixdata2* and *Badpixdata3* to locate pixels where the pixel value is greater than 1.01 times or less than 0.99 times the median in the 9×9 neighborhood pixels. These pixels are marked as non-uniform pixels.

8.7.6 *Persistence/Lag Pixel*—The first image where the complete image is dark (the image after the one with large dark and bright areas, or the first completely dark image) shall be selected for the evaluation. The following procedure may be followed to compute the persistence/lag pixel.

8.7.6.1 Use a 9×9 mask over the image to locate if the pixel value is greater than two times the median value in 9×9 neighboring pixels and greater than six times the median value σ_m as computed in 8.7.4.1. Such pixels are defined as persistence/lag pixels.

8.7.7 *Bad Neighborhood Pixel*—A correctly-responding pixel where all eight neighboring pixels are bad pixels.

8.8 *Calculation of Internal Scatter Radiation*—A line profile shall be done over the sharp edge of the copper plate in the acquired image (Fig. 11). The result shall be extracted from the line profile as:

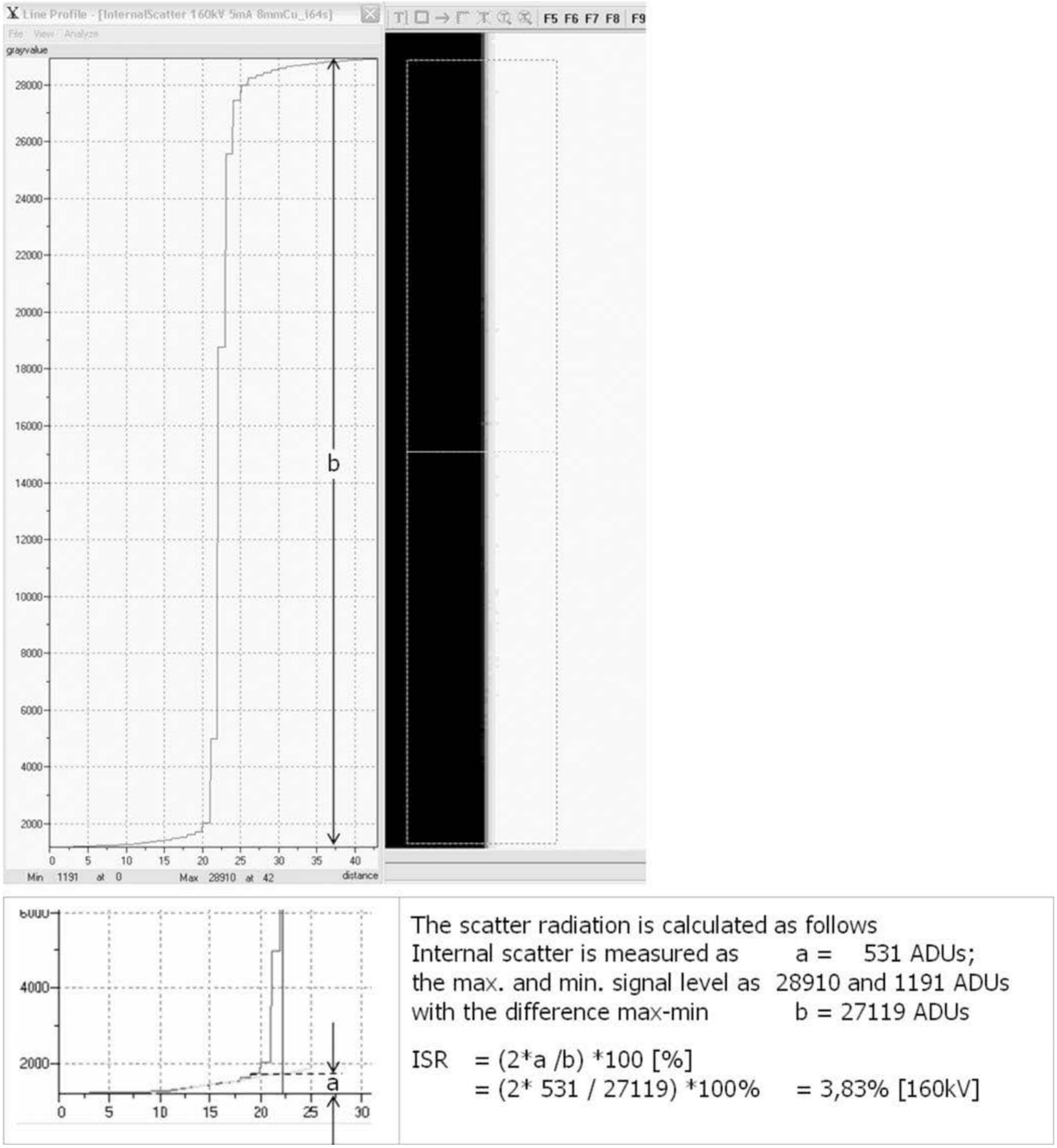
$$ISR = (2 \times a/b) \times 100\% \quad (6)$$

where:

ISR = measure of internal scatter radiation,
a = long-range unsharpness contribution, and
b = signal level beside the copper plate.

9. Display of the Results of the Manufacturer Tests

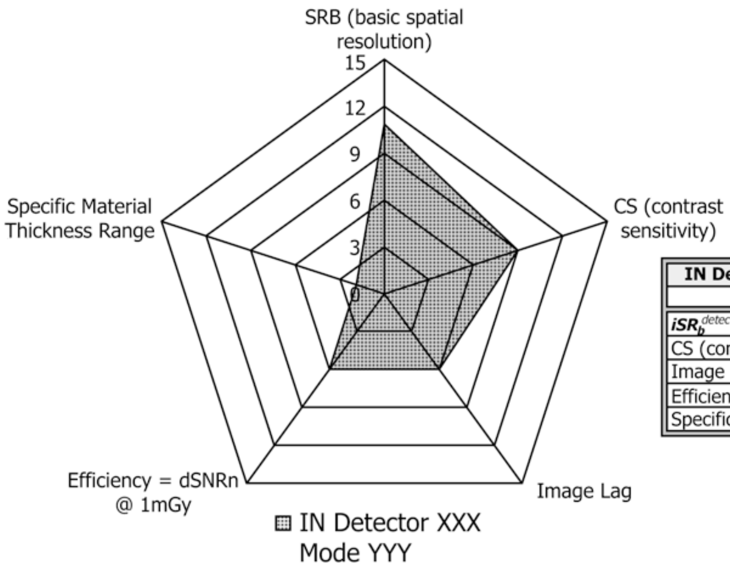
9.1 All results shall be made available, including complete data sheets and graphs/tables of the testing in accordance with Appendix X1. Similarly, summary charts and tables can be provided that list the results under a standard set of parameters. To make the results more digestible, the results can also be presented in the net diagram described below. As an example, five of the seven parameters are included: Basic Spatial Resolution, Efficiency, Achievable Contrast Sensitivity, Specific Material Thickness Range, and Lag of the DDA from Section 8. These parameters are weighted in a range from 0 (low) to 25 (high) to arrive at a quality factor. Table 2



NOTE 1—"a" is the long range unsharpness contribution and "b" is the signal level outside the copper plate.

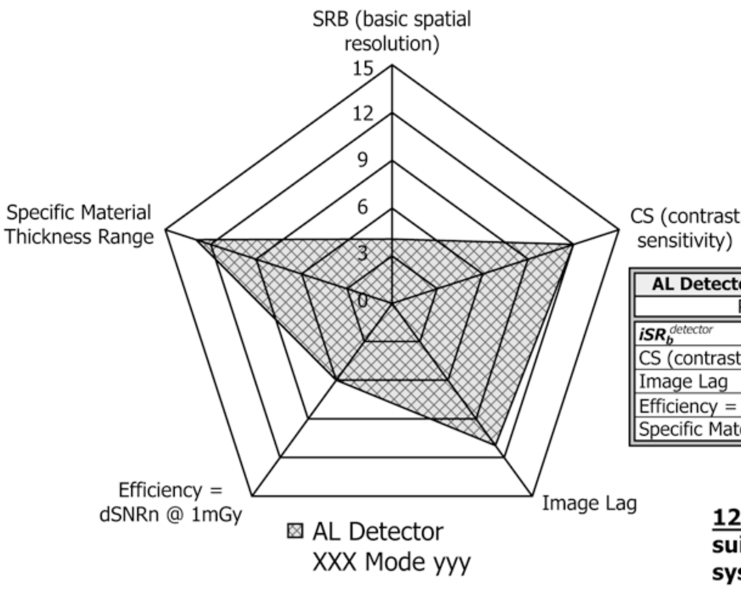
FIG. 11 Internal Scatter Radiation Measurement

represents the quality factor representation of the measured parameters for the three different materials. The measured value for each of the parameters shall be mathematically rounded to the quality factor of the nearest bounding value. The bad pixel information is not included as its importance is highly dependent on the application. The internal scatter results are not included for similar reasons. Two examples are shown in Fig. 12a-d. Fig. 12a refers to a DDA suitable for inspection of flat material with high resolution with a moderate efficiency, for example for small welds. Fig. 12b refers to a DDA suitable



IN Detector XXX Mode yyy			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	67	**11**
CS (contrast sensitivity)	[%]	0,38	**9**
Image Lag	[%]	0,72	**6**
Efficiency = dSNRn @ 1mGy		470	**6**
Specific Material Thickness Range	[mm]	4,2	**2**

12a. Example DDA potentially suitable for weld inspection.



AL Detector XXX Mode yyy			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	392	**4**
CS (contrast sensitivity)	[%]	0,176	**12**
Image Lag	[%]	0,21	**11**
Efficiency = dSNRn @ 1mGy		570	**6**
Specific Material Thickness Range	[mm]	92	**13**

12b. Example DDA potentially suitable fast automatic inspection systems for aluminum castings

FIG. 12 Net Summary Plots of Some of the Measured Parameters

for fast automatic inspection systems for aluminium castings with the requirement of high contrast sensitivity, large specific material thickness range and moderate image lag.

10. Classification of the DDAs

10.1 The manufacturer shall report the *dSNRn* and the *iSRb* for each detector type using the following guidelines to match results from CR and film classification standards (Test Method E1815 and Practice E2446).

10.1.1 *dSNRn* with beam quality of 220 kV (8 mm copper) as defined in 7.8 and basic spatial resolution (*iSRb*) in accordance with 7.7.

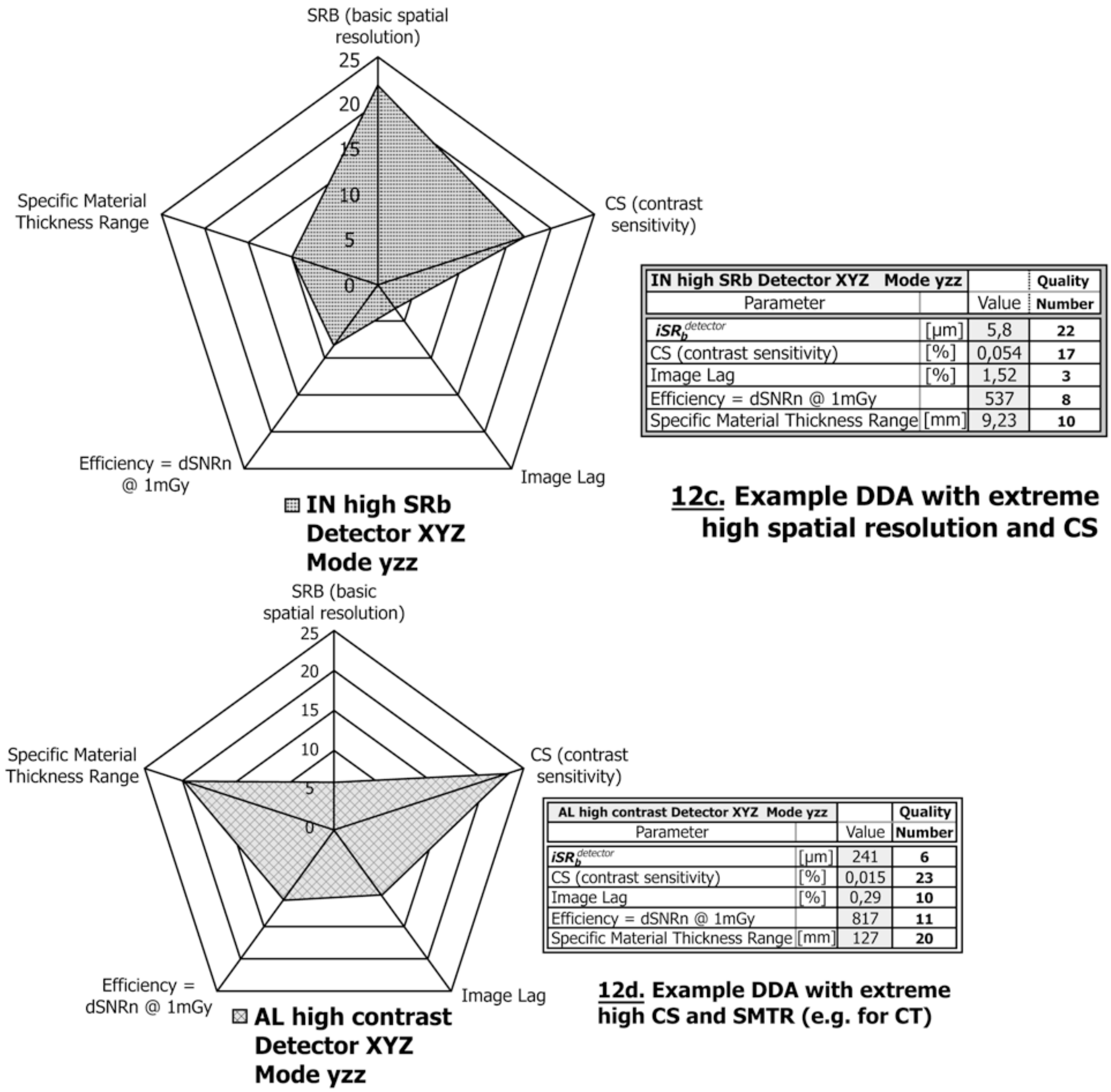
10.1.2 DDAs that cannot be used at X-ray voltage of 220 kV (8 mm copper) due to manufacturer's restriction may be classified at lower, but maximum permissible radiation energy, with a beam filter of no less than 3 mm of copper.

10.1.3 A classification requires the statement of two values:

10.1.3.1 The minimum required *dSNRn* value in accordance to Table 1 of Practice E2446 and the corresponding dose (or equivalence value as given by distance, X-ray tube current (mA) × exposure time (s) and material thickness) at the detector.

10.1.3.2 The statement of the *iSRb* value of this practice (see 7.7 and 8.2).

NOTE 10—The classification values of *dSNRn* are shown in Table 3 but shall be given always with *iSRb*.



IN high SRb Detector XYZ Mode yzz			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	5,8	**22**
CS (contrast sensitivity)	[%]	0,054	**17**
Image Lag	[%]	1,52	**3**
Efficiency = dSNRn @ 1mGy		537	**8**
Specific Material Thickness Range	[mm]	9,23	**10**

AL high contrast Detector XYZ Mode yzz			Quality
Parameter		Value	Number
$iSR_b^{detector}$	[µm]	241	**6**
CS (contrast sensitivity)	[%]	0,015	**23**
Image Lag	[%]	0,29	**10**
Efficiency = dSNRn @ 1mGy		817	**11**
Specific Material Thickness Range	[mm]	127	**20**

FIG. 12 Net Summary Plots of Some of the Measured Parameters *(continued)*

TABLE 3 Minimum *dSNRn* Values for DDA Classes to Compare with CR-Systems and Film Systems

DDA System Classes	Minimum *dSNRn* Values	Necessary Dose	mAs @ 1 m Distance
DDA Special	130		
DDA I	65		
DDA II	52		
DDA III	43		

11. Precision and Bias

11.1 No statement is made about either the precision or bias of this practice for characterizing DDA systems. The results merely state whether there is conformance to the criteria for success specified in the procedure.

12. Keywords

12.1 bad pixels; basic spatial resolution; burn-in; contrast sensitivity; DDA; efficiency; image lag; normalized SNR; SNR; specific material thickness range

APPENDIX

(Nonmandatory Information)

X1. INPUT AND OUTPUT DATA SHEETS

X1.1 Input data sheet should be documented using the following format for each test:

Data Sheet (Input)

Detector	
Make	____________
Model	____________
Detector Internal Settings	____________
X-ray Tube	
Make	____________
Model	____________
Target material	____________
Focal spot dimension used	____________
Inherent beam filtration (material and thickness)	____________
Geometry	
Source-Detector distance	____________
Source-Object (center) distance	____________
Exposure	
Pre-filter material and thickness	____________
X-ray tube voltage	____________
X-ray tube current	____________
Exposure time (per frame)	____________
Number of frames averaged	____________
Total (effective exposure time)	____________
Radiation Quality	**Dose Rate**
No filter	____________
30 mm [1.2 in.] aluminum filter and 90 kV	____________
40 mm [1.6 in.] aluminum filter and 120 kV	____________
3 mm [0.12 in.] copper filter and 120 kV	____________
10 mm [0.4 in.] iron filter and 160 kV	____________
8 mm [0.3 in.] copper filter and 220 kV	____________
16 mm [0.6 in.] copper filter and 220 kV	____________
Calibration	
Offset subtraction	____________
Gain correction (flat field)	____________
Bad-pixel correction	____________
Any other calibrations or corrections	____________

X1.2 Output data sheet should be documented using the following format:

Data Sheet (Output)

A Basic spatial resolution *iSRb*, measured as described in section 7.7 and calculated as shown in section 8.2.

Example: iSRb = 189 µm.

B Efficiency at different energies as described in section 7.8 and calculated in section 8.3.
The *dSNRn* values at 1 mGy for the 5 or 6 different energy levels shall be documented.

Example:

Energy	50 kV	90 kV 30 Al	120 kV 40 Al	120 kV 3 Cu	160 kV 10 Fe	220 kV 8 Cu
dSNRn @ 1 mGy	654	850	886	682	744	408

C Achievable Contrast Sensitivity, measured as described in section 7.9 and calculated as shown in section 8.4, is presented in a tabular form.
The data can be plotted for each material, CSa as a function of thicknesses or be displayed in a table. See Fig. 7.

Example Aluminium: X-ray tube setting: 160 kV, 6 mA and pre-filter used 0.5 mm Cu.

[mm Al]	1 s	4 s	16 s	64 s
10	0,187%	0,157%	0,152%	0,152%
20	0,165%	0,140%	0,133%	0,133%
40	0,171%	0,131%	0,118%	0,115%
60	0,258%	0,163%	0,125%	0,114%
80	0,551%	0,293%	0,184%	0,144%
100	1,272%	0,616%	0,354%	0,247%

D Specific Material Thickness Range, measured as described in section 7.10 and calculated as shown in section 8.5, for 1% and 2% sensitivity with each material.

Example: See Fig. 8.

E1 Image Lag, normalized to 1 s and after 60 s, measured as described in section 7.11.1 and calculated as shown in section 8.6.1.

Example: GlobalLag1s = 0.73%; GlobalLag60s = 0.027%.

E2 Burn-In, measured as described in section 7.11.2 and calculated as shown in section 8.6.2.

Example:

Burn-in after	1 minute	1 hour	4 hours	24 hours
[%]	3.8	2.7	1.8	1.4

F Bad Pixels are measured as described in section 7.12 and evaluated as shown in section 8.6.1.
The manufacturer creates a list of the test of several systems and presents the results in a table.
Number of detectors used for reporting a typical value should be documented.

Example: (each detector has 4.000.000 pixel; bad pixels summary given is a mean value obtained from 10 detectors).

Bad Pixel reason	No Response	Out of Range	Noise	Lag	Bad Neighbors
Typical values [%]	0.002	0.025	0.002	0.05	0

Additionally, the manufacturer presents the typical values of Relevant Clusters (RCl), Irrelevant Clusters (ICl) and Bad Line Segments (BLS).

Example:

Groups of Bad Pixel	Relevant Cluster	Irrelevant Clusters	Bad Line Segments
Typical values	2,72	47,6	0.53 full lines

G Displaying the results of Internal Scatter Radiation measurement as described in sections 7.13 and 8.8.

Example: ISR = 3.83% [at 160 kV].

H Displaying the results of A, C, E1, B, and D in a net diagram as shown in Section 9.

Examples: See Fig. 12.

Note—The manufacturer may present the results of tests with 1, 2, or all 3 different materials: Aluminum, Steel and Titanium.

ARTICLE 23
ULTRASONIC STANDARDS

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF STEEL FORGINGS

(19)

SA-388/SA-388M

(Identical with ASTM Specification A388/A388M-16a.)

Standard Practice for Ultrasonic Examination of Steel Forgings

1. Scope

1.1 This practice covers the examination procedures for the contact, pulse-echo ultrasonic examination of steel forgings by the straight and angle-beam techniques. The straight beam techniques include utilization of the DGS (Distance Gain-Size) method. See Appendix X3.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that forgings are to be subject to ultrasonic examination in accordance with Practice A388/A388M.

1.3 Supplementary requirements of an optional nature are provided for use at the option of the purchaser. The supplementary requirements shall apply only when specified individually by the purchaser in the purchase order or contract.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 This specification and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation [SI units], the material shall be furnished to inch-pound units.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A469/A469M Specification for Vacuum-Treated Steel Forgings for Generator Rotors

A745/A745M Practice for Ultrasonic Examination of Austenitic Steel Forgings

A788/A788M Specification for Steel Forgings, General Requirements

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing

E1065/E1065M Practice for Evaluating Characteristics of Ultrasonic Search Units

2.2 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, (1988 or later)

3. Terminology

3.1 *Definitions:*

3.1.1 *indication levels (clusters), n*—five or more indications in a volume representing a 2-in. [50-mm] or smaller cube in the forging.

3.1.2 *individual indications, n*—single indications showing a decrease in amplitude as the search unit is moved in any direction from the position of maximum amplitude and which are too small to be considered traveling or planar.

3.1.3 *planar indications, n*—indications shall be considered continuous over a plane if they have a major axis greater than 1 in. [25 mm] or twice the major dimension of the transducer, whichever is greater, and do not travel.

3.1.4 *traveling indications, n*—inductions whose leading edge moves a distance equivalent to 1 in. [25 mm] or more of metal depth with movement of the transducer over the surface of the forging.

4. Significance and Use

4.1 This practice shall be used when ultrasonic inspection is required by the order or specification for inspection purposes where the acceptance of the forging is based on limitations of the number, amplitude, or location of discontinuities, or a combination thereof, which give rise to ultrasonic indications.

4.2 The ultrasonic quality level shall be clearly stated as order requirements.

5. Ordering Information

5.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and shall also furnish the following information:

5.1.1 Designation number (including year date),

5.1.2 Method of establishing the sensitivity in accordance with 9.2.2 and 9.3.3 (DGS (Distance Gain Size), Vee- or rectangular-notch),

5.1.2.1 The diameter and test metal distance of the flat-bottom hole and the material of the reference block in accordance with 9.2.2.2,

5.1.3 Quality level for the entire forging or portions thereof in accordance with 12.3, and

5.1.4 Any options in accordance with 1.5, 6.4, 6.5, 7.1, 8.1, 8.2, 9.1.11, 10.1, 10.2, and 12.2.

6. Apparatus

6.1 *Electronic Apparatus*—An ultrasonic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for examining at frequencies from 1 to 5 MHz. On examining austenitic stainless forgings the system shall have the capabilities for examining at frequencies down to 0.4 MHz.

6.1.1 *Apparatus Qualification and Calibration*—Basic qualification of the ultrasonic test instrument shall be performed at intervals not to exceed 12 months or whenever maintenance is performed that affects the equipment function. The date of the last calibration and the date of the next required calibration shall be displayed on the test equipment.

6.1.2 The ultrasonic instrument shall provide linear presentation (within 5 %) for at least 75 % of the screen height (sweep line to top of screen). The 5 % linearity referred to is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E317. Any set of blocks processed in accordance with Practice E317 or E428 may be used to establish the specified ±5 % instrument linearity.

6.1.3 The electronic apparatus shall contain an attenuator (accurate over its useful range to ±10 % (+1 dB) of the amplitude ratio) which will allow measurement of indications beyond the linear range of the instrument.

6.2 *Search Units*, having a transducer with a maximum active area of 1 in.^{2} [650 mm^2] with ¾ in. [20 mm] minimum to 1⅛ in. [30 mm] maximum dimensions shall be used for straight-beam scanning (see 9.2); and search units with ½ in. [13 mm] minimum to 1 in. [25 mm] maximum dimensions shall be used for angle-beam scanning (see 9.3).

6.2.1 *Transducers* shall be utilized at their rated frequencies.

6.2.2 Other search units may be used for evaluating and pinpointing indications.

6.3 *Couplants*, having good wetting characteristics such as SAE No. 20 or No. 30 motor oil, glycerin, pine oil, or water shall be used. Couplants may not be comparable to one another and the same couplant shall be used for calibration and examination.

6.4 *Reference Blocks*, containing flat-bottom holes may be used for calibration of equipment in accordance with 6.1.2 and may be used to establish recording levels for straight-beam examination when so specified by the order or contract.

6.5 *DGS Scales*, matched to the ultrasonic test unit and transducer to be utilized, may be used to establish recording levels for straight or angle beam examination, when so specified by the order or contract. The DGS scale range must be selected to include the full thickness cross-section of the forging to be examined. An example of a DGS overlay is found in Appendix X3.

6.5.1 As an alternative to using DGS overlays, an ultrasonic instrument having DGS software, integral decibel gain or attenuator controls in combination with a specifically paired transducer and DGS diagram may be used to evaluate ultrasonic indications.

7. Personnel Requirements

7.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A (1988 or later) or another national standard that is acceptable to both the purchaser and the supplier.

8. Preparation of Forging for Ultrasonic Examination

8.1 Unless otherwise specified in the order or contract, the forging shall be machined to provide cylindrical surfaces for radial examination in the case of round forgings; the ends of the forgings shall be machined perpendicular to the axis of the forging for the axial examination. Faces of disk and rectangular forgings shall be machined flat and parallel to one another.

8.2 The surface roughness of exterior finishes shall not exceed 250 µin. [6 µm] where the definition for surface finish is as per Specification A788/A788M unless otherwise shown on the forging drawing or stated in the order or the contract.

8.3 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, and so forth.

9. Procedure

9.1 *General:*

9.1.1 As far as practicable, subject the entire volume of the forging to ultrasonic examination. Because of radii at change of sections and other local configurations, it may be impossible to examine some sections of a forging.

9.1.2 Perform the ultrasonic examination after heat treatment for mechanical properties (exclusive of stress-relief treatments) but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to contour. If the configuration of the forging required for the treatment for mechanical properties prohibits a subsequent complete examination of the forging, it shall be permissible to examine prior to treatment for mechanical properties. In such cases, reexamine the forging ultrasonically as completely as possible after heat treatment.

9.1.3 To ensure complete coverage of the forging volume, index the search unit with at least 15 % overlap with each pass.

9.1.4 For manual scanning, do not exceed a scanning rate of 6 in./s [150 mm/s].

9.1.5 For automated scanning, adjust scanning speed or instrument repetition rate, or both, to permit detection of the smallest discontinuities referenced in the specification and to allow the recording or signaling device to function. At no time shall the scanning speed exceed the speed at which an acceptable calibration was made.

9.1.6 If possible, scan all sections of forgings in two perpendicular directions.

9.1.7 Scan disk forgings using a straight beam technique from at least one flat face and radially from the circumference, whenever practicable.

9.1.8 Scan cylindrical sections and hollow forgings radially using a straight-beam technique. When practicable, also examine the forging in the axial direction.

9.1.9 In addition, examine hollow forgings by angle-beam technique from the outside diameter surface as required in 9.3.1.

9.1.10 In rechecking or reevaluation by manufacturer or purchaser, use comparable equipment, search units, frequency, and couplant.

9.1.11 Forgings may be examined either stationary or while rotating in a lathe or on rollers. If not specified by the purchaser, either method may be used at the manufacturer's option.

9.2 *Straight-Beam Examination:*

9.2.1 For straight-beam examination use a nominal 2¼-MHz search unit whenever practicable; however, 1 MHz is the preferred frequency for coarse grained austenitic materials and long testing distances. In many instances on examining coarse grained austenitic materials it may be necessary to use a frequency of 0.4 MHz. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws.

9.2.2 Establish the instrument sensitivity by either the reflection, reference-block technique, or DGS method (see Appendix X3 for an explanation of the DGS method).

9.2.2.1 *Back-Reflection Technique (Back-Reflection Calibration Applicable to Forgings with Parallel Entry and Back Surfaces)*—Use the back reflection from the opposite side of the part as a calibration standard to set the sensitivity for the test. The two surfaces (entry surface and the reflecting surface) must be parallel to each other. Place the transducer in an area of the forging, when possible, so that the geometry will not have an effect on the beam spread. Increase the gain to obtain a 75 % full screen height back reflection, increase the gain by up to an additional 20 dB (10:1). If no indications are present (indication free) return the gain to the original dB setting of the 75 % full screen height (1:1), this will be the reference level. Scanning should be done at a level greater than the reference level, such as 6 dB (2:1). During the scanning, the back reflection shall be monitored for any significant loss of amplitude not attributed to the geometry. Carry out the evaluation of discontinuities with the gain control set at the reference level (75 % full screen height). Recalibration is required for significant changes in section thickness or diameter.

NOTE 1—High sensitivity levels are not usually employed when inspecting austenitic steel forgings due to attendant high level of "noise" or "hash" caused by coarse grain structure.

9.2.2.2 *Reference-Block Calibration*—The test surface roughness on the calibration standard shall be comparable to, but no better than, the item to be examined. Adjust the instrument controls to obtain the required signal amplitude from the flat-bottom hole in the specified reference block. Utilize the attenuator in order to set up on amplitudes larger than the vertical linearity of the instrument. In those cases, remove the attenuation prior to scanning the forging.

NOTE 2—When flat-surfaced reference block calibration is specified, adjust the amplitude of indication from the reference block or blocks to compensate for examination surface curvature (an example is given in Appendix X1).

9.2.2.3 *DGS Calibration*—Prior to use, verify that the DGS overlay or electronic DGS curve matches the transducer size and frequency. Accuracy of the overlay can be verified by reference blocks and procedures outlined in Practice E317. Overlays are to be serialized to match the ultrasonic transducer and pulse echo testing system that they are to be utilized with. Instruments with electronic DGS must use the specified ultrasonic transducer for that electronic curve.

(1) Electronic DGS—Modern test instruments with DGS software are particularly easy to calibrate. Most ultrasonic test instruments with DGS software have 13 standard probes and corresponding DGS diagrams stored in the instrument. There are also custom settings by which the operator may program their own data sets. The operator may choose from flat bottomed hole, side drilled hole or back reflection to use for calibration. The instructions from the test instruments operator's manual for DGS calibration must be followed to properly calibrate the instrument. Operator errors are largely excluded due to the display of on screen messages.

(2) Upon input of all necessary parameters for the flaw evaluation, the corresponding curve will be electronically displayed on the instrument screen. This method of calibration may be used for longitudinal (single and dual) and shear wave examination.

9.2.2.4 Choose the appropriate DGS scale for the cross-sectional thickness of the forging to be examined. Insert the overlay over the CRT screen, ensuring the DGS scale base line coincides with the sweep line of the CRT screen. Place the probe on the forging, adjust the gain to make the first back-wall echo appear clearly on CRT screen. Using the Delay and Sweep control, shift the screen pattern so that the leading edge of the initial pulse is on zero of the DGS scale and the back-wall echo is on the DGS scale value corresponding to the thickness of the forging. Adjust the gain so the forging back-wall echo matches the height of the DGS reference slope within ±1 Db. Once adjusted, increase the gain by the Db shown on the DGS scale for the reference slope. Instrument is now calibrated and flaw sizes that can be reliably detected can be directly read from the CRT screen. These flaw sizes are the equivalent flat bottom reflector that can be used as a reference point.

NOTE 3—The above can be utilized on all solid forgings. Cylindrical hollow forgings, and drilled or bored forgings must be corrected to compensate for attenuation due to the central hole (see Appendix X4).

9.2.3 *Recalibration*—Any change in the search unit, couplant, instrument setting, or scanning speed from that used for calibration shall require recalibration. Perform a calibration check at least once every 8 h shift. When a loss of 15 % or greater in the gain level is indicated, reestablish the required calibration and reexamine all of the material examined in the preceding calibration period. When an increase of 15 % or greater in the gain level is indicated, reevaluate all recorded indications.

9.2.4 During the examination of the forging, monitor the back reflection for any significant reduction in amplitude. Reduction in back-reflection amplitude may indicate not only the presence of a discontinuity but also poor coupling of the search unit with the surface of the forging, nonparallel back-reflection surface, or local variations of attenuation in the forging. Recheck any areas causing loss of back reflection.

9.3 *Angle-Beam Examination—Rings and Hollow Forgings:*

9.3.1 Perform the examination from the circumference of rings and hollow forgings that have an axial length greater than 2 in. [50 mm] and an outside to inside diameter ratio of less than 2.0 to 1.

9.3.2 Use a 1 MHz, 45° angle-beam search unit unless thickness, OD/ID ratio, or other geometric configuration results in failure to achieve calibration. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws. For angle-beam inspection of hollow forgings up to 2.0 to 1 ratio, provide the transducer with a wedge or shoe that will result in the beam mode and angle required by the size and shape of the cross section under examination.

9.3.3 *Calibration for Angle-Beam Examination:*

9.3.3.1 *Calibration with a Physical Notch*—Calibrate the instrument for the angle-beam examination to obtain an indication amplitude of approximately 75 % full-screen height from a rectangular or a 60° V-notch on inside diameter (ID) in the axial direction and parallel to the axis of the forging. A separate calibration standard may be used; however, it shall have the same nominal composition, heat treatment, and thickness as the forging it represents. The test surface finish on the calibration standard shall be comparable but no better than the item to be examined. Where a group of identical forgings is made, one of these forgings may be used as the separate calibration standard. Cut the ID notch depth to 3 % maximum of the thickness or ¼ in. [6 mm], whichever is smaller, and its length approximately 1 in. [25 mm]. Thickness is defined as the thickness of the forging to be examined at the time of examination. At the same instrument setting, obtain a reflection from a similar OD notch. Draw a line through the peaks of the first reflections obtained from the ID and OD notches. This shall be the amplitude reference line. It is preferable to have the notches in excess metal or test metal when possible. When the OD notch cannot be detected when examining the OD surface, perform the examination when practicable (some ID's may be too small to permit examination), as indicated above from both the OD and ID surfaces. Utilize the ID notch when inspecting from the OD, and the OD notch when inspecting from the ID. Curve wedges or shoes may be used when necessary and practicable.

9.3.3.2 *Electronic DGS Calibration for Angle Beam*—Prior to use verify that the electronic DGS curve matches the transducer size and frequency. Accuracy of the curve can be verified by reference blocks and procedures outlined in Practice E317. Angle beam calibration can be established by use of flat bottom holes, side drilled holes, notches or the back reflection. Separate test blocks may be employed provided they are machined with a reflecting surface. Square-, U- or V-shaped notches, side drilled or flat bottom holes maybe machined into the test block for this purpose. For the back reflection calibration a concave curved surface such as contained on an IIW, K1, or V1 test block may be used.

9.3.4 Perform the examination by scanning over the entire surface area circumferentially in both the clockwise and counter-clockwise directions from the OD surface. Examine forgings, which cannot be examined axially using a straight beam, in both axial directions with an angle-beam search unit. For axial scanning, use rectangular or 60° V-notches on the ID and OD for the calibration. These notches shall be perpendicular to the axis of the forging and the same dimensions as the axial notch.

10. Recording

10.1 *Straight-Beam Examination*—Record the following indications as information for the purchaser. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order or contract.

10.1.1 For individual indications, report:

10.1.1.1 In the back-reflection technique, individual indications equal to or exceeding 10 % of a nominal back reflection from an adjacent area free from indications, and

10.1.1.2 In the reference-block or DGS technique, indications equal to or exceeding 100 % of the reference amplitude.

10.1.2 For indications that are planar, traveling, or clustered, determine the location of the edges and the major and minor axes using the half-amplitude (6 dB drop) technique and report:

10.1.2.1 The variation in depth or planar area, or both, of traveling indications,

10.1.2.2 The length of major and minor axes of planar indications, and

10.1.2.3 The volume occupied by indication levels and the amplitude range.

10.2 *Angle-Beam Examination*—Record discontinuity indications equal to or exceeding 50 % of the indication from the reference line. When an amplitude reference line cannot be generated, record discontinuity indications equal to or exceeding 50 % of the reference notch. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

10.3 Report reduction in back reflection exceeding 50 % of the original measured in increments of 10 %.

10.4 When recording, corrections must be made for beam divergence at the estimated flaw depth (See Practice E1065/E1065M).

10.5 Report indication amplitudes in increments of 10 %.

11. Report

11.1 Report the following information:

11.1.1 All recordable indications (see Section 10);

11.1.2 For the purpose of reporting the locations of recordable indications, a sketch shall be prepared showing the physical outline of the forging including dimensions of all areas not inspected due to geometric configuration, the purchaser's drawing number, the purchaser's order number, and the manufacturer's serial number, and the axial, radial, and circumferential distribution of recordable ultrasonic indications;

11.1.3 The designation (including year date) to which the examination was performed as well as the frequency used, method of setting sensitivity, type of instrument, surface finish, couplant, and search unit employed; and

11.1.4 The inspector's name or identity and date the examination was performed.

12. Quality Levels

12.1 This practice is intended for application to forgings, with a wide variety of sizes, shapes, compositions, melting processes, and applications. It is, therefore, impracticable to specify an ultrasonic quality level which would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual forgings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in the production of the particular type forging.

12.2 Austenitic stainless steel forgings are more difficult to penetrate ultrasonically than similar carbon or low-alloy steel forgings. The degree of attenuation normally increases with section size; and the noise level, generally or in isolated areas, may become too great to permit detection of discrete indications. In most instances, this attenuation results from inherent coarse grained microstructure of these austenitic alloys. For these reasons, the methods and standards employed for ultrasonically examining carbon and low-alloy steel forgings may not be applicable to austenitic steel forgings. In general, only straight beam inspecting using a back-reflection reference standard is used. However, utilization of Practice A745/A745M for austenitic steel forgings can be considered if flat bottom hole reference standards or angle beam examination of these grades are required.

12.3 Acceptance quality levels shall be established between purchaser and manufacturer on the basis of one or more of the following criteria.

12.3.1 *Straight-Beam Examination:*

12.3.1.1 No indications larger than some percentage of the reference back reflection.

12.3.1.2 No indications equal to or larger than the indication received form the flat-bottom hole in a specific reference block or blocks.

12.3.1.3 No areas showing loss of back reflection larger than some percentage of the reference back reflection.

12.3.1.4 No indications per 12.3.1.1 or 12.3.1.2 coupled with some loss of resultant back reflection per 12.3.1.3.

12.3.1.5 No indications exceeding the reference level specified in the DGS method.

12.3.2 *Angle-Beam Examination*—No indications exceeding a stated percentage of the reflection from a reference notch or of the amplitude reference line.

12.4 Intelligent application of ultrasonic quality levels involves an understanding of the effects of many parameters on examination results.

13. Keywords

13.1 angle beam examination; back-reflection; DGS; reference-block; straight beam examination; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details shall be agreed upon by the manufacturer and the purchaser.

S1. Reporting Criteria

S1.1 Reference block calibration shall be performed using at least three holes, spaced to approximate minimum, mean, and maximum thickness as tested, and shall be used to generate a distance amplitude correction (DAC) curve. The following hole sizes apply:

1. 1⁄16 in. [1.5 mm] flat bottom holes (FBH) for thicknesses less than 1.5 in. [40 mm]
2. 1⁄8 in. [3 mm] FBH for thicknesses of 1.5-6 in. [40-150 mm] inclusive
3. 1⁄4 in. [6 mm] FBH for thicknesses over 6 in. [150 mm]

S1.2 Reporting criteria include:

1. All indications exceeding the DAC curve
2. Two or more indications separated by 1⁄2 in. [12 mm] or less

S2. Use of Dual Element Transducers

S2.1 Dual-element transducers shall be used to inspect those regions of a forging where the presence of a bore, taper or other feature prevents scanning the near field region, of the single element transducers used, from the opposite surface.

S2.2 Dual-element transducers shall be used to inspect areas near the back-wall of forgings where indications caused by noise exceed the reporting requirements shown in 10.5.

S3. Surface Finish

S3.1 The surface finish shall not exceed 125 µin (3.17 µm) where the definition for surface finish is as per Specification A788/A788M.

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL TUNING LEVEL COMPENSATION FOR THE EFFECTS OF FORGING CURVATURE

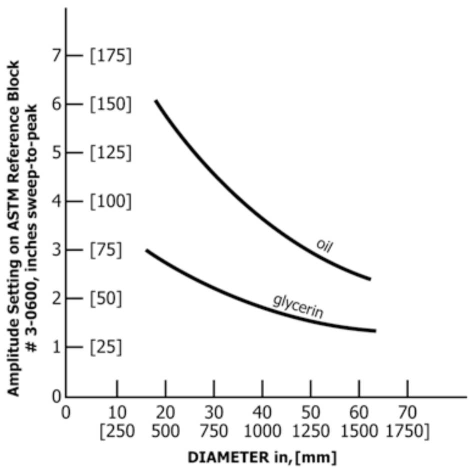


FIG. X1.1 Typical Compensation Curve for Effects of Forging Curvature

X1.1 The curve (Fig. X1.1) was determined for the following test conditions:

Material	nickel-molybdenum-vanadium alloy steel (Specification A469/A469M, Class 4)
Instrument	Type UR Reflectoscope
Search unit	1⅛-in. [30-mm] diameter quartz
Frequency	2¼ MHz
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [6.5 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 µin. [6 µm], max, roughness

X1.2 To utilize curve, adjust reflectoscope sensitivity to obtain indicated ultrasonic response on ASTM No. 3-0600 reference block for each diameter as shown. A response of 1 in. [25 mm] sweep-to-peak is used for flat surfaces. Use attenuator to obtain desired amplitude, but do testing at 1 to 1 setting.

X2. INDICATION AMPLITUDE COMPENSATION FOR TEST DISTANCE VARIATIONS

X2.1 The curve (Fig. X2.1) has been determined for the following test conditions:

Material	nickel-molybdenum-vanadium alloy steel (Specification A469/A469M, Class 4)
Instrument	Type UR Reflectoscope
Search unit	1⅛-in. [30-mm] diameter quartz
Frequency	2¼ MHz
Couplant	No. 20 oil
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [65 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 µin. max, roughness

X2.2 To utilize curve, establish amplitude from ASTM reference block to coincide with values from Appendix X1.

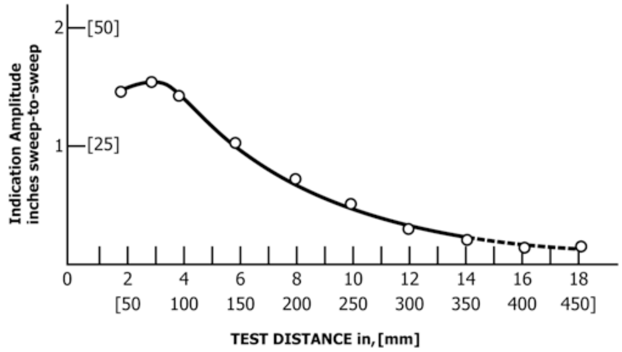


FIG. X2.1 Typical Distance-Amplitude Correction Curve

X3. BACKGROUND INFORMATION ON THE DGS METHODS

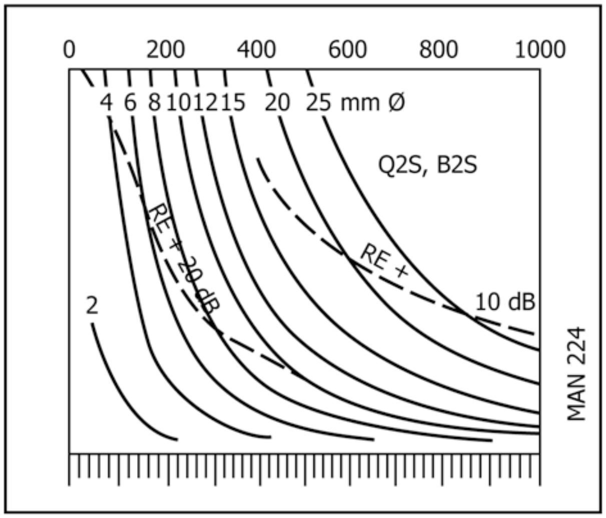


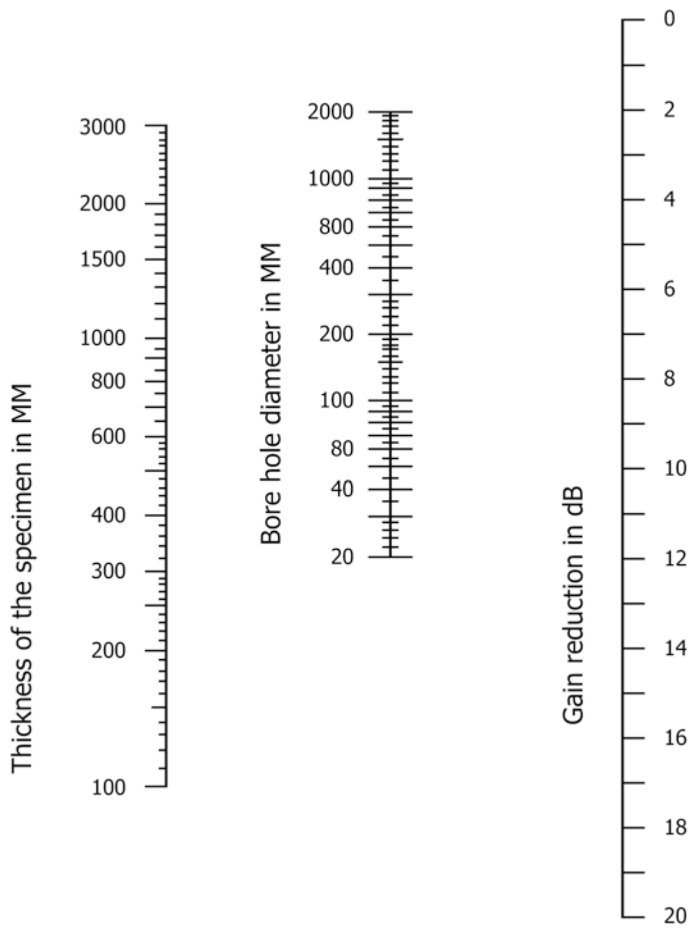
FIG. X3.1 Example of DGS Overlay

X3.1 The overlay in Fig. X3.1 was designed for a 2.0 MHz, 1 in. [25 mm] diameter probe and a maximum test distance of 39.4 in. [1000 mm]. In order to use this overlay, the sweep time base must be accurately calibrated and aligned with the overlay being used. The back reflection is then adjusted to either the RE + 10 dB line or the RE + 20 dB line, based on the thickness being tested; additional gain (10 or 20 dB) is added as designated by the line being used. The RE + 20 line covers a range to approximately 15.7 in. [400 mm] and the RE + 10 line from 15.7 to 39.4 in. [400 to 1000 mm]. At this calibration level, the flaw size is read directly from the screen. Flaw sizes from 0.078 to 1 in. [2 to 25 mm] can be read directly from the overlay.

X4. COMPENSATION FOR CENTER HOLE ATTENUATION ON CYLINDRICAL BORED OR HOLLOW FORGINGS UTILIZING THE DGS METHOD

X4.1 The hole in a cylindrical bored forging causes sound scatter. In these cases, a correction is required which depends on the wall thickness and bore diameter.

X4.1.1 Determine the correction value in dB from the Nomogram (Fig. X4.1). With the gain-dB control, proceed as described in 9.2.2.4 reducing the flaw detector gain by the correction value determined.



NOTE 1—Metric units are presented in this figure to be consistent with DGS scales presently available. Conversion to English units would also be acceptable.

FIG. X4.1 The Influence of a Central Bore on the Backwall Echo Amplitude of Cylindrical or Plane Parallel Forgings

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STANDARD SPECIFICATION FOR STRAIGHT-BEAM ULTRASONIC EXAMINATION OF STEEL PLATES

(**19**) SA-435/SA-435M

(Identical with ASTM Specification A435/A435M-17.)

Standard Specification for
Straight-Beam Ultrasonic Examination of Steel Plates

1. Scope

1.1 This specification covers the procedure and acceptance standards for straight-beam, pulse-echo, ultrasonic examination of rolled fully killed carbon and alloy steel plates, ½ in. [12.5 mm] and over in thickness. It was developed to assure delivery of steel plates free of gross internal discontinuities such as pipe, ruptures, or laminations and is to be used whenever the inquiry, contract, order, or specification states that the plates are to be subjected to ultrasonic examination.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents, therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E1316 Terminology for Nondestructive Examinations

E2491 Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems

2.2 *ASNT Documents:*

ASNT SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Terminology

3.1 *Definitions*—For definitions of terms relating to nondestructive examinations used in this specification, refer to Terminology E1316.

4. Apparatus

4.1 The manufacturer shall furnish suitable ultrasonic equipment and qualified personnel necessary for performing the test. The equipment shall be of the pulse-echo straight beam type. The transducer is normally 1 to 1⅛ in. [25 to 30 mm] in diameter or 1 in. [25 mm] square; however, any transducer having a minimum active area of 0.7 in.^{2} [450 mm^2] may be used, including phased-array probes using an equivalent active aperture. The test shall be performed by one of the following methods: direct contact, immersion, or liquid column coupling.

4.2 Other search units may be used for evaluating and pinpointing indications.

4.3 Vertical or horizontal linearity or both shall be checked in accordance with Practice E317, Guide E2491, or another procedure approved by the users of this specification. An acceptable linearity performance may be agreed upon by the manufacturer and purchaser.

5. Test Conditions

5.1 Conduct the examination in an area free of operations that interfere with proper functioning of the equipment.

5.2 Clean and smooth the plate surface sufficiently to maintain a reference back reflection from the opposite side of the plate at least 50 % of the full scale during scanning.

5.3 The surface of plates inspected by this method may be expected to contain a residue of oil or rust or both. Any specified identification which is removed when grinding to achieve proper surface smoothness shall be restored.

6. Procedure

6.1 Ultrasonic examination shall be made on either major surface of the plate. Acceptance of defects in close proximity may require inspection from the second major surface. Plates ordered in the quenched and tempered condition shall be tested following heat treatment.

6.2 A nominal test frequency of 2¼ MHz is recommended. Thickness, grain size, or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. However, frequencies less than 1 MHz may be used only on agreement with the purchaser. A clear, easily interpreted A-scan should be produced during the examination.

6.3 Conduct the examination with a test frequency and instrument adjustment that will produce a minimum 50 to a maximum 75 % of full scale reference back reflection from the opposite side of a sound area of the plate.

6.4 Scanning shall be continuous along perpendicular grid lines on nominal 9-in. [225-mm] centers, or at the manufacturer's option, shall be continuous along parallel paths, transverse to the major plate axis, on nominal 4-in. [100-mm] centers, or shall be continuous along parallel paths parallel to the major plate axis, on 3-in. [75-mm] or smaller centers. A suitable couplant such as water, soluble oil, or glycerin, shall be used.

6.5 Scanning lines shall be measured from the center or one corner of the plate. An additional path shall be scanned within 2 in. [50 mm] of all edges of the plate on the scanning surface.

6.6 Where grid scanning is performed and complete loss of back reflection accompanied by continuous indications is detected along a given grid line, the entire surface area of the squares adjacent to this indication shall be scanned. Where parallel path scanning is performed and complete loss of back reflection accompanied by continuous indications is detected, the entire surface area of a 9 by 9-in. [225 by 225-mm] square centered on this indication shall be scanned. The true boundaries where this condition exists shall be established in either method by the following technique: Move the transducer away from the center of the discontinuity until the heights of the back reflection and discontinuity indications are equal. Mark the plate at a point equivalent to the center of the transducer. Repeat the operation to establish the boundary.

7. Acceptance Standards

7.1 Any discontinuity indication causing a total loss of back reflection which cannot be contained within a circle, the diameter of which is 3 in. [75 mm] or one half of the plate thickness, whichever is greater, is unacceptable.

7.2 The manufacturer reserves the right to discuss rejectable ultrasonically tested plates with the purchaser with the object of possible repair of the ultrasonically indicated defect before rejection of the plate.

7.3 The purchaser's representative may witness the test.

8. Marking

8.1 Plates accepted in accordance with this specification shall be identified by stamping or stenciling UT 435 adjacent to marking required by the material specification.

9. Keywords

9.1 nondestructive testing; pressure containing parts; pressure vessel steels; steel plate for pressure vessel applications; steel plates; straight-beam; ultrasonic examinations

SUPPLEMENTARY REQUIREMENTS

The following shall apply only if specified in the order:

S1. Instead of the scanning procedure specified by 6.4 and 6.5, and as agreed upon between manufacturer and purchaser, 100 % of one major plate surface shall be scanned. Scanning shall be continuous along parallel paths, transverse or parallel to the major plate axis, with not less than 10 % overlap between each path.

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STANDARD SPECIFICATION FOR ULTRASONIC ANGLE-BEAM EXAMINATION OF STEEL PLATE

(19)

SA-577/SA-577M

(Identical with ASTM Specification A577/A577M-17.)

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee

Standard Specification for Ultrasonic Angle-Beam Examination of Steel Plate

1. Scope

1.1 This specification covers an ultrasonic angle-beam procedure and acceptance standards for the detection of internal discontinuities not laminar in nature and of surface imperfections in a steel plate. This specification is intended for use only as a supplement to specifications which provide straight-beam ultrasonic examination.

NOTE 1—An internal discontinuity that is laminar in nature is one whose principal plane is parallel to the principal plane of the plate.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E1316 Terminology for Nondestructive Examinations

E2491 Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems

2.2 *ASNT Standards:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Terminology

3.1 *Definitions*—For definitions of terms relating to nondestructive examinations used in this specification, refer to Terminology E1316.

4. Ordering Information

4.1 The inquiry and order shall indicate any additions to the provisions of this specification as prescribed in 12.1.

5. Examination Conditions

5.1 The examination shall be conducted in an area free of operations that interfere with proper performance of the examination.

5.2 The surface of the plate shall be conditioned as necessary to provide a clear, easily interpreted A-scan on the screen of the ultrasonic instrument. Any specified identification which is removed to achieve proper surface smoothness shall be restored.

6. Apparatus

6.1 *Ultrasonic Instruments:*

6.1.1 The ultrasonic instrument shall be a pulse echo type instrument capable of addressing either a mono-element probe or a phased-array probe and shall be equipped with a standardized dB gain or attenuation control stepped in increments of 1 dB minimum. The system shall be capable of generating and displaying A-scans.

6.2 Vertical and horizontal linearity and amplitude control linearity shall be checked in accordance with Practice E317, Guide E2491, or another procedure approved by the users of this specification. An acceptable linearity performance may be agreed upon by the manufacturer and purchaser.

6.3 The search unit shall be a 45-deg (in steel) angle-beam type with active transducer length and width dimensions of a minimum of ½ in. [12.5 mm] and a maximum of 1 in. [25 mm]. When phased-array systems are used, focal laws using an equivalent active aperture shall be used. Search units of other sizes and angles may be used for additional exploration and evaluation.

7. Examination Frequency

7.1 A nominal test frequency of 5 MHz is recommended. Thickness, grain size, or microstructure of the material and nature of the equipment or method may permit a higher or require a lower examination frequency. The ultrasonic frequency selected for the examination shall permit detection of the required calibration notch, such that the amplitude of the indication yields a signal-to-noise ratio of at least 3:1.

8. Calibration Reflector

8.1 A calibration notch, the geometry of which has been agreed upon by the purchaser and the manufacturer, with a depth of 3 % of the plate thickness, shall be used to calibrate the ultrasonic examination. The notch shall be at least 1 in. [25 mm] long.

8.2 Machine the notch or notches on the surface of the plate so that they are perpendicular to the long axis at a distance of 2 in. [50 mm] or more from the short edge of the plate. Locate the notch not less than 2 in. [50 mm] from the long edges of the plate.

8.3 When the notch cannot be machined in the plate to be tested, it may be placed in a calibration plate of ultrasonically similar material. The calibration plate will be considered ultrasonically similar if the height of the first back reflection of a straight-beam through its thickness is within 25 % of that through the plate to be tested at the same instrument calibration. The calibration plate thickness shall be within 1 in. [25 mm] of the thickness of plates to be tested, for plates of 2 in. [50 mm] thickness and greater and within 10 % of plates whose thickness is less than 2 in. [50 mm].

8.4 For plate thicknesses greater than 2 in. [50 mm], machine a second calibration notch as described in 8.2 or 8.3, as applicable, on the opposite side of the plate.

9. Calibration Procedure

9.1 *Plate 2 in. [50 mm] and Under in Thickness:*

9.1.1 Place the search unit on the notched surface of the plate with the sound beam directed at the broad side of the notch and maximize the response from the first vee-path indication. Adjust the instrument gain so that this reflection amplitude is at least 50 but not more than 80 % of full screen height. Record the location and amplitude of this indication on the screen.

9.1.2 Move the search unit away from the notch until the second vee-path indication is obtained. Maximize the response and record the indication amplitude. Draw a line between the peaks from the two successive notch indications on the screen. This line is the distance amplitude correction (DAC) curve for this material and shall be a 100 % reference line for reporting indication amplitudes. Alternatively the second vee-path indication may be set to equalize its amplitude to the first vee-path signal using time-corrected gain.

9.2 *Plate Over 2 to 6 in. [50 to 150 mm] Inclusive in Thickness:*

9.2.1 Place the search unit on the test surface aimed at the broad side of the notch on the opposite surface of the plate. Maximize the one-half vee-path indication amplitude. Adjust the instrument gain so that this amplitude is at least 50 % but not more than 80 % of full screen height. Record the location and amplitude on the screen. Without adjusting the instrument settings, repeat this procedure for the 1½ vee-path indication.

9.2.2 Without adjusting the instrument settings, maximize the full vee-path indication from the notch on the test surface. Record the location and amplitude on the screen.

9.2.3 Draw a line on the screen connecting the points established in 9.2.1 and 9.2.2. This curve shall be a DAC curve for reporting indication amplitudes. Alternatively the vee-path indication and ½ vee-path indication may be set to equalize the amplitudes to the one-half vee-path signal using time-corrected gain.

9.3 *Plate Over 6 in. [150 mm] in Thickness:*

9.3.1 Place the search unit on the test surface aimed at the broad side of the notch on the opposite surface of the plate. Maximize the one-half vee-path indication amplitude. Adjust the instrument gain so that this amplitude is at least 50 % but not more than 80 % of full screen height. Record the location and amplitude on the screen.

9.3.2 Without adjusting the instrument settings, reposition the search unit to obtain a maximum full vee-path indication from the notch on the test surface. Record the location and amplitude on the screen.

9.3.3 Draw a line on the screen connecting the points established in 9.3.1 and 9.3.2. This line shall be a DAC curve for reporting indication amplitudes. Alternatively the vee-path indication may be set to equalize the amplitude to the one-half veepath signal using time-corrected gain.

10. Examination Procedure

10.1 Scan one major surface of the plate on grid lines perpendicular and parallel to the major rolling direction. Grid lines shall be on 9-in. [225-mm] centers. Use a suitable couplant such as water, oil, or glycerin. Scan by placing the search unit near one edge with the ultrasonic beam directed toward the same edge and move the search unit along the grid line in a direction perpendicular to the edge to a location two plate thicknesses beyond the plate center. Repeat this scanning procedure on all grid lines from each of the four edges.

10.2 Measure grid lines from the center or one corner of the plate.

10.3 Position the search unit to obtain a maximum indication amplitude from each observed discontinuity.

10.4 For each discontinuity indication that equals or exceeds the 100 % reference line, record the location and length, and the amplitude to the nearest 25 %. No indication with amplitude less than the 100 % reference shall be recorded.

10.5 At each recorded discontinuity location, conduct a 100 % examination of the volume under a 9-in. [225-mm] square which has the recorded discontinuity position at its center. Conduct the examination in directions perpendicular and parallel to the major rolling direction.

11. Acceptance Standard

11.1 Any discontinuity indication that equals or exceeds the 100 % reference shall be considered unacceptable unless additional exploration by the longitudinal method indicates it is laminar in nature.

12. Report

12.1 Unless otherwise agreed upon between the purchaser and manufacturer, the manufacturer shall report the following data:

12.1.1 Plate identity including pin-pointed recordable indication locations, lengths, and amplitudes.

12.1.2 Examination parameters, including: couplant; search unit type, angle, frequency, and size; instrument make, model, and serial number; and calibration plate description.

12.1.3 Date of examination and name of operator.

13. Inspection

13.1 The purchaser's representative shall have access, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the ultrasonic examination of the material ordered. The manufacturer shall afford the representative all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All examinations and verifications shall be conducted so as not to interfere unnecessarily with the manufacturer's operations.

14. Rehearing

14.1 The manufacturer reserves the right to discuss unacceptable ultrasonically examined plate with the purchaser with the object of possible repair of the ultrasonically indicated discontinuity before rejection of the plate.

15. Marking

15.1 Plates accepted in accordance with this specification shall be identified by metal stamping or stenciling "UT A577" in one corner of the plate, at a location within 6 in. [150 mm] of the heat number.

16. Keywords

16.1 angle beams; steel plates; ultrasonic examination

STANDARD SPECIFICATION FOR STRAIGHT-BEAM ULTRASONIC EXAMINATION OF ROLLED STEEL PLATES FOR SPECIAL APPLICATIONS

(19)

SA-578/SA-578M

(Identical with ASTM Specification A578/A578M-17.)

Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications

1. Scope

1.1 This specification covers the procedure and acceptance standards for straight-beam, pulse-echo, ultrasonic examination of rolled carbon and alloy steel plates, ³⁄₈ in. [10 mm] in thickness and over, for special applications. The method will detect internal discontinuities parallel to the rolled surfaces. Three levels of acceptance standards are provided. Supplementary requirements are provided for alternative procedures.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

A263 Specification for Stainless Chromium Steel-Clad Plate
A264 Specification for Stainless Chromium-Nickel Steel-Clad Plate
A265 Specification for Nickel and Nickel-Base Alloy-Clad Steel Plate
E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments
E1316 Terminology for Nondestructive Examinations
E2491 Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems

2.2 *ANSI Standard:*

B 46.1 Surface Texture

2.3 *ASNT Standard:*

SNT-TC-1A

3. Terminology

3.1 *Definitions*—For definitions of terms relating to nondestructive examinations used in this specification, refer to Terminology E1316.

4. Ordering Information

4.1 The inquiry and order shall indicate the following:

4.1.1 Acceptance level requirements (Sections 8, 9, and 10). Acceptance Level B shall apply unless otherwise agreed to by purchaser and manufacturer.

4.1.2 Any additions to the provisions of this specification as prescribed in 6.2, 14.1, and Section 11.

4.1.3 Supplementary requirements, if any.

5. Apparatus

5.1 The ultrasonic instrument shall be a pulse echo type instrument capable of addressing either a mono-element probe or a phased-array probe and shall be equipped with a standardized dB gain or attenuation control stepped in increments of 1 dB minimum. The system shall be capable of generating and displaying A-scans.

5.2 Vertical and horizontal linearity and amplitude control linearity shall be checked in accordance with Practice E317, Guide E2491, or another procedure approved by the users of this specification. An acceptable linearity performance may be agreed upon by the manufacturer and purchaser.

5.3 The transducer shall be 1 or 1⅛ in. [25 or 30 mm] in diameter or 1 in. [25 mm] square. When phased-array systems are used, focal laws using an equivalent active aperture shall be used.

5.4 Other search units may be used for evaluating and pinpointing indications.

6. Procedure

6.1 Perform the inspection in an area free of operations that interfere with proper performance of the test.

6.2 Unless otherwise specified, make the ultrasonic examination on either major surface of the plate.

6.3 The plate surface shall be sufficiently clean and smooth to maintain a first reflection from the opposite side of the plate at least 50 % of full scale during scanning. This may involve suitable means of scale removal at the manufacturer's option. Condition local rough surfaces by grinding. Restore any specified identification which is removed when grinding to achieve proper surface smoothness.

6.4 Perform the test by one of the following methods: direct contact, immersion, or liquid column coupling. Use a suitable couplant such as water, soluble oil, or glycerin. As a result of the test by this method, the surface of plates may be expected to have a residue of oil or rust or both.

6.5 A nominal test frequency of 2¼ MHz is recommended. When testing plates less than ¾ in. [20 mm] thick a frequency of 5 MHz may be necessary. Thickness, grain size or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. Use the transducers at their rated frequency. A clean, easily interpreted A-scan display should be produced during the examination.

6.6 *Scanning:*

6.6.1 Scanning shall be along continuous perpendicular grid lines on nominal 9-in. [225-mm] centers, or at the option of the manufacturer, shall be along continuous parallel paths, transverse to the major plate axis, on nominal 4-in. [100-mm] centers, or shall be along continuous parallel paths parallel to the major plate axis, on 3-in. [75-mm] or smaller centers. Measure the lines from the center or one corner of the plate with an additional path within 2 in. [50 mm] of all edges of the plate on the examination surface.

6.6.2 Conduct the general scanning with an instrument adjustment that will produce a first reflection from the opposite side of a sound area of the plate from 50 to 90 % of full scale. Minor sensitivity adjustments may be made to accommodate for surface roughness.

6.6.3 When a discontinuity condition is observed during general scanning adjust the instrument to produce a first reflection from the opposite side of a sound area of the plate of 75 ± 5 % of full scale. Maintain this instrument setting during evaluation of the discontinuity condition.

7. Recording

7.1 Record all discontinuities causing complete loss of back reflection.

7.2 For plates ¾ in. [20 mm] thick and over, record all indications with amplitudes equal to or greater than 50 % of the initial back reflection and accompanied by a 50 % loss of back reflection.

NOTE 1—Indications occurring midway between the initial pulse and the first back reflection may cause a second reflection at the location of the first back reflection. When this condition is observed it shall be investigated additionally by use of multiple back reflections.

7.3 Where grid scanning is performed and recordable conditions as in 7.1 and 7.2 are detected along a given grid line, the entire surface area of the squares adjacent to this indication shall be scanned. Where parallel path scanning is performed and recordable conditions as in 7.1 and 7.2 are detected, the entire surface area of a 9 by 9-in. [225 by 225-mm] square centered on this indication shall be scanned. The true boundaries where these conditions exist shall be established in either method by the following technique: Move the transducer away from the center of the discontinuity until the height of the back reflection and discontinuity indications are equal. Mark the plate at a point equivalent to the center of the transducer. Repeat the operation to establish the boundary.

8. Acceptance Standard—Level A

8.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane (within 5 % of plate thickness) that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or ½ of the plate thickness, whichever is greater, is unacceptable.

9. Acceptance Standards—Level B

9.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane (within 5 % of plate thickness) that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or ½ of the plate thickness, whichever is greater, is unacceptable.

9.2 In addition, two or more discontinuities smaller than described in 9.1 shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger discontinuity or unless they may be collectively encompassed by the circle described in 9.1.

10. Acceptance Standard—Level C

10.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane (within 5 % of plate thickness) that cannot be encompassed within a 1-in. [25-mm] diameter circle is unacceptable.

11. Report

11.1 Unless otherwise agreed to by the purchaser and the manufacturer, the manufacturer shall report the following data:

11.1.1 All recordable indications listed in Section 7 on a sketch of the plate with sufficient data to relate the geometry and identity of the sketch to those of the plate.

11.1.2 Test parameters including: Make and model of instrument, surface condition, search unit (type and frequency), and couplant.

11.1.3 Date of test.

12. Inspection

12.1 The inspector representing the purchaser shall have access at all times, while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the ultrasonic testing of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be conducted without interfering unnecessarily with the manufacturer's operations.

13. Rehearing

13.1 The manufacturer reserves the right to discuss rejectable ultrasonically tested plate with the purchaser with the object of possible repair of the ultrasonically indicated defect before rejection of the plate.

14. Marking

14.1 Plates accepted according to this specification shall be identified by stenciling (stamping) "UT A578—A" on one corner for Level A, "UT A578—B" for Level B, and "UT A578—C" for Level C. The supplement number shall be added for each supplementary requirement ordered.

15. Keywords

15.1 nondestructive testing; pressure containing parts; pressure vessel steels; steel plate for pressure vessel applications; steel plates; straight-beam; ultrasonic examinations

SUPPLEMENTARY REQUIREMENTS

These supplementary requirements shall apply only when individually specified by the purchaser. When details of these requirements are not covered herein, they are subject to agreement between the manufacturer and the purchaser.

S1. Scanning

S1.1 Scanning shall be continuous over 100 % of the plate surface along parallel paths, transverse or parallel to the major plate axis, with not less than 10 % overlap between each path.

S2. Acceptance Standard

S2.1 Any recordable condition listed in Section 7 that (*1*) is continuous, (*2*) is on the same plane (within 5 % of the plate thickness), and (*3*) cannot be encompassed by a 3-in. [75-mm] diameter circle, is unacceptable. Two or more recordable conditions (see Section 7), that (*1*) are on the same plane (within 5 % of plate thickness), (*2*) individually can be encompassed by a 3-in. [75-mm] diameter circle, (*3*) are separated from each other by a distance less than the greatest dimension of the smaller indication, and (*4*) collectively cannot be encompassed by a 3-in. [75-mm] diameter circle, are unacceptable.

S2.2 An acceptance level more restrictive than Section 8 or 9 shall be used by agreement between the manufacturer and purchaser.

S3. Procedure

S3.1 The manufacturer shall provide a written procedure in accordance with this specification.

S4. Certification

S4.1 The manufacturer shall provide a written certification of the ultrasonic test operator's qualifications.

S5. Surface Finish

S5.1 The surface finish of the plate shall be conditioned to a maximum 125 μin. [3 μm] AA (see ANSI B 46.1) prior to test.

S6. Withdrawn

See Specifications A263, A264, and A265 for equivalent descriptions for clad quality level.

S7. Withdrawn

See Specifications A263, A264, and A265 for equivalent descriptions for clad quality level.

S8. Ultrasonic Examination Using Flat Bottom Hole Calibration (for Plates 4 in. [100 mm] Thick and Greater)

S8.1 Use the following calibration and recording procedures in place of 6.6.2, 6.6.3, and Section 7.

S8.2 The transducer shall be in accordance with 5.3.

S8.3 *Reference Reflectors*—The $T/4$, $T/2$, and $3T/4$ deep flat bottom holes shall be used to calibrate the equipment, where T is the thickness of the plate. The flat bottom hole diameter shall be in accordance with Table S8.1. The holes may be drilled in

TABLE S8.1 Calibration Hole Diameter as a Function of Plate Thickness (S8)

Plate Thickness, in. [mm]	4–6 [100–150]	>6–9 [>150–225]	>9–12 [>225–300]	>12–20 [>300–500]
Hole Diameter, in. [mm]	5/8 [16]	3/4 [19]	7/8 [22]	1 1/8 [29]

the plate to be examined if they can be located without interfering with the use of the plate, in a prolongation of the plate to be examined, or in a reference block of the same nominal composition, and thermal treatment as the plate to be examined. The surface of the reference block shall be no better to the unaided eye than the plate surface to be examined. The reference block shall be of the same nominal thickness (within 75 % to 125 % or 1 in. [25 mm] of the examined plate, whichever is less) and shall have acoustical properties similar to the examined plate. Acoustical similarity is presumed when, without a change in instrument setting, comparison of the back reflection signals between the reference block and the examined plate shows a variation of 25 % or less.

S8.4 *Calibration Procedure:*

S8.4.1 Couple and position the search unit for maximum amplitudes from the reflectors at *T*/4, *T*/2, and 3*T*/4. Set the instrument to produce a 75 ± 5 % of full scale indication from the reflector giving the highest amplitude.

S8.4.2 Without changing the instrument setting, couple and position the search unit over each of the holes and mark on the screen the maximum amplitude from each hole and each minimum remaining back reflection.

S8.4.3 Mark on the screen half the vertical distance from the A-scan base line to each maximum amplitude hole mark. Connect the maximum amplitude hole marks and extend the line through the thickness for the 100 % DAC (distance amplitude correction curve). Similarly connect and extend the half maximum amplitude marks for the 50 % DAC. Alternatively, when time-corrected gain (TCG) is used, the responses from the flat bottom holes shall be equalized at 75 % screen height (±5 %) and the half-amplitude noted.

S8.5 *Recording:*

S8.5.1 Record all areas where the remaining back reflection is smaller than the highest of the minimum remaining back reflections found in S8.4.2.

S8.5.2 Record all areas where indications exceed 50 % DAC or 50 % TCG.

S8.5.3 Where recordable conditions listed in S8.5.1 and S8.5.2 are detected along a given grid line, continuously scan the entire surface area of the squares adjacent to the condition and record the boundaries or extent of each recordable condition.

S8.6 Scanning shall be in accordance with 6.6.

S8.7 The acceptance levels of Section 8 or 9 shall apply as specified by the purchaser except that the recordable condition shall be as given in S8.5.

S9. Ultrasonic Examination of Electroslag Remelted (ESR) and Vacuum-Arc Remelted (VAR) Plates, from 1 to 16 in. [25 to 400 mm] in Thickness, Using Flat-Bottom Hole Calibration and Distance-Amplitude Corrections

S9.1 The material to be examined must have a surface finish of 200 µin. [5 µm] as maximum for plates up to 8 in. [200 mm] thick, inclusive, and 250 µin. [6 µm] as maximum for plates over 8 to 16 in. [200 to 400 mm] thick.

S9.2 Use the following procedures in place of 6.6.1, 6.6.2, 6.6.3, and Section 7.

S9.3 The transducer shall be in accordance with 5.3.

S9.4 *Reference Reflectors*—The *T*/4, *T*/2, and 3*T*/4 deep flat bottom holes shall be used to calibrate the equipment, where T is the thickness of the plate. The flat bottom hole diameter shall be in accordance with Table S9.1. The flat bottoms of the holes shall be within 1° of parallel to the examination surface. The holes may be drilled in the plate to be examined if they can be located without interfering with the use of the plate, in a prolongation of the plate to be examined, or in a reference block of the same nominal composition and thermal treatment as the plate to be examined. The surface of the reference block shall be no better to the unaided eye than the plate surface to be examined. The reference block shall be of the same nominal thickness (within 75 % to 125 % or 1 in. [25 mm] of the examined plate, whichever is less) and shall have acoustical properties similar to the examined plate. Acoustical similarity is presumed when, without a change in instrument setting, comparison of the back reflection signals between the reference block and the examined plate shows a variation of 25 % or less.

S9.5 *Calibration Procedure:*

S9.5.1 Couple and position the search unit for maximum amplitudes from the reflectors at *T*/4, *T*/2, and 3*T*/4. Set the instrument to produce a 75 ± 5 % of full-scale indication from the reflector giving the highest amplitude.

S9.5.2 Without changing the instrument setting, couple and position the search unit over each of the holes and mark on the screen the maximum amplitude from each of the holes.

S9.5.3 Mark on the screen half the vertical distances from the sweep line to each maximum amplitude hole mark. Connect the maximum amplitude hole marks and extend the line through the thickness for the 100 % DAC (distance amplitude correction curve). Similarly connect and extend the half maximim amplitude marks for the 50 % DAC. Alternatively, when time-corrected gain (TCG) is used, the responses from the flat bottom holes shall be equalized at 75 % screen height (±5 %) and the half-amplitude noted.

S9.6 *Scanning* —Scanning shall cover 100 % of one major plate surface, with the search unit being indexed between each pass such that there is at least 15 % overlap of adjoining passes in order to assure adequate coverage for locating discontinuities.

S9.7 *Recording*—Record all areas where the back reflection drops below the 50 % DAC or 50 % TCG. If the drop in back reflection is not accompanied by other indications on the screen, recondition the surface in the area and reexamine ultrasonically. If the back reflection is still below 50 % DAC, the loss may be due to the metallurgical structure of the material being examined. The material shall be held for metallurgical review by the purchaser and manufacturer.

S9.8 *Acceptance Standards*—Any indication that exceeds the 100 % DAC or 100 % TCG shall be considered unacceptable. The manufacturer may reserve the right to discuss

TABLE S9.1 Calibration Hole Diameter as a Function of Plate Thickness (S9)

Plate Thickness, in. [mm]	1–4 [25–100]	>4–8 [>100–200]	>8–12 [>200–300]	>12–16 [>300–400]
Hole Diameter, in. [mm]	1/8 [3]	1/4 [6]	3/8 [10]	1/2 [13]

rejectable ultrasonically examined material with the purchaser, the object being the possible repair of the ultrasonically indicated defect before rejection of the plate.

STANDARD PRACTICE FOR CASTINGS, CARBON, LOW-ALLOY AND MARTENSITIC STAINLESS STEEL, ULTRASONIC EXAMINATION THEREOF

SA-609/SA-609M

(Identical with ASTM Specification A609/A609M-12 except for errata corrections to Note B in Table 4 and in the third column head of Table S1.1.)

Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof

1. Scope

1.1 This practice covers the standards and procedures for the pulse-echo ultrasonic examination of heat-treated carbon, low-alloy, and martensitic stainless steel castings.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that castings are to be subjected to ultrasonic examination in accordance with Practice A609/A 609M.

1.3 This practice contains two procedures. Procedure A is the original A609/A609M practice and requires calibration using a series of test blocks containing flat bottomed holes. It also provides supplementary requirements for angle beam testing. Procedure B requires calibration using a back wall reflection from a series of solid calibration blocks.

NOTE 1—Ultrasonic examination and radiography are not directly comparable. This examination technique is intended to complement Guide E94 in the detection of discontinuities.

1.4 Supplementary requirements of an optional nature are provided for use at the option of the purchaser. The supplementary requirements shall apply only when specified individually by the purchaser in the purchase order or contract.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5.1 Within the text, the SI units are shown in brackets.

1.5.2 This practice is expressed in both inch-pound units and SI units; however, unless the purchase order or contract specifies the applicable M specification designation (SI units), the inch-pound units shall apply.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A217/A217M Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service

E94 Guide for Radiographic Examination

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

2.2 *Other Document:*

SNT-TC-1A Recommended Practice for Non-Destructive Testing Personnel Qualification and Certification

3. Ordering Information

3.1 The inquiry and order should specify which procedure is to be used. If a procedure is not specified, Procedure A shall be used.

3.2 The purchaser shall furnish the following information:

3.2.1 Quality levels for the entire casting or portions thereof,

3.2.2 Sections of castings requiring longitudinal-beam examination,

3.2.3 Sections of castings requiring dual element examination,

3.2.4 Sections of castings requiring supplementary examination, using the angle-beam procedure described in Supplementary Requirement S1 in order to achieve more complete examination, and

3.2.5 Any requirements additional to the provisions of this practice.

PROCEDURE A—FLAT-BOTTOMED HOLE CALIBRATION PROCEDURE

4. Apparatus

4.1 *Electronic Apparatus:*

4.1.1 An ultrasonic, pulsed, reflection type of instrument that is capable of generating, receiving, and amplifying frequencies of at least 0.5 to 5 MHz.

4.1.2 The ultrasonic instrument shall provide linear presentation (within ±5 %) for at least 75 % of the screen height (sweep line to top of screen). Linearity shall be determined in accordance with Practice E317 or equivalent electronic means.

4.1.3 The electronic apparatus shall contain a signal attenuator or calibrated gain control that shall be accurate over its useful range to ±10 % of the nominal attenuation or gain ratio to allow measurement of signals beyond the linear range of the instrument.

4.2 *Search Units:*

4.2.1 *Longitudinal Wave,* internally grounded, having a ½ to 1 in. [13 to 25 mm] diameter or 1-in. [25-mm] square piezo-electric elements. Based on the signals-to-noise ratio of the response pattern of the casting, a frequency in the range from 0.5 to 5 MHz shall be used. The background noise shall not exceed 25 % of the distance amplitude correction curve (DAC). Transducers shall be utilized at their rated frequencies.

4.2.2 *Dual-Element,* 5-MHz, ½ by 1-in. [13 by 25-mm], 12° included angle search units are recommended for sections 1 in. [25 mm] and under.

4.2.3 Other frequencies and sizes of search units may be used for evaluating and pinpointing indications.

4.3 *Reference Blocks:*

4.3.1 Reference blocks containing flat-bottom holes shall be used to establish test sensitivity in accordance with 8.2.

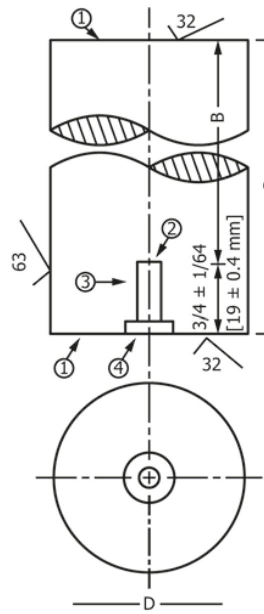
4.3.2 Reference blocks shall be made from cast steels that give an acoustic response similar to the castings being examined.

4.3.3 The design of reference blocks shall be in accordance with Fig. 1, and the basic set shall consist of those blocks listed in Table 1. When section thicknesses over 15 in. [380-mm] are to be inspected, an additional block of the maximum test thickness shall be made to supplement the basic set.

4.3.4 Machined blocks with 3⁄32-in. [2.4-mm] diameter flat-bottom holes at depths from the entry surface of ⅛ in. [3 mm], ½ in. [13 mm], or ½ *t* and ¾ in. [19 mm], or ¾ *t* (where *t* = thickness of the block) shall be used to establish the DAC for the dual-element search units (see Fig. 2).

4.3.5 Each reference block shall be permanently identified along the side of the block indicating the material and the block identification.

4.4 *Couplant*—A suitable couplant having good wetting characteristics shall be used between the search unit and examination surface. The same couplant shall be used for calibrations and examinations.



NOTE 1—Opposite ends of reference block shall be flat and parallel within 0.001 in. [0.025 mm].

NOTE 2—Bottom of flat-bottom hole shall be flat within 0.002-in. [0.051 mm] and the finished diameter shall be ¼ + 0.002 in. [6.4 + 0.050].

NOTE 3—Hole shall be straight and perpendicular to entry surface within 0°, 30 min and located within 1⁄32 in. [0.80 mm] of longitudinal axis.

NOTE 4—Counter bore shall be ½ in. [15.0 mm] diameter by ⅛ in. [5 mm] deep.

FIG. 1 Ultrasonic Standard Reference Block

TABLE 1 Dimensions and Identification of Reference Blocks in the Basic Set (See Fig. 1)

Hole Diameter in 1⁄64 ths, in. [mm]	Metal Distance *(B)*, in.[A] [mm]	Overall Length *(C)*, in. [mm]	Width or Diameter *(D)*, min, in. [mm]	Block Identification Number
16 [6.4]	1 [25]	1¾ [45]	2 [50]	16-0100
16 [6.4]	2 [50]	2¾ [70]	2 [50]	16-0200
16 [6.4]	3 [75]	3¾ [95]	2 [50]	16-0300
16 [6.4]	6 [150]	6¾ [170]	3 [75]	16-0600
16 [6.4]	10 [255]	10¾ [275]	4 [100]	16-1000
16 [6.4]	B	B + ¾ [B + 20]	5 [125]	16-B00[B]

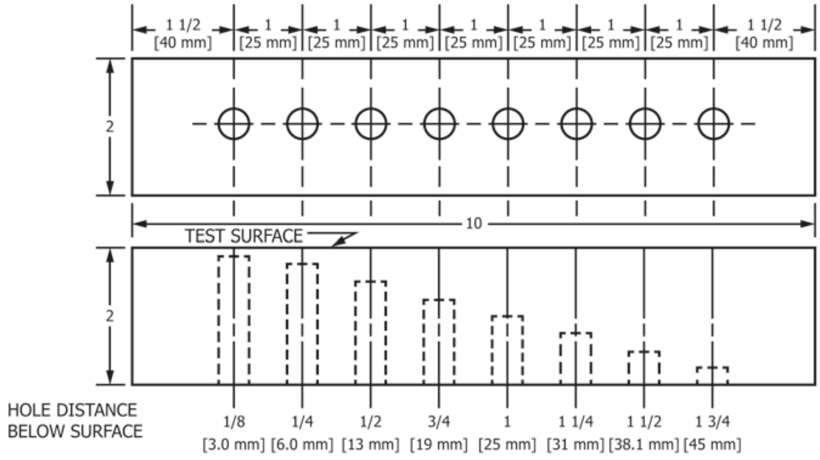
[A] Tolerance ±⅛ in. [3 mm].
[B] Additional supplemental blocks for testing thickness greater than 10 in. [250 mm], see 4.3.3.

5. Personnel Requirements

5.1 Personnel performing ultrasonic examination in accordance with this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard acceptable to both the purchaser and the supplier.

6. Casting Conditions

6.1 Castings shall receive at least an austenitizing heat treatment before being ultrasonically examined.



NOTE 1—Entrant surface shall be 250 µin. [6.3 µm] or finer.

NOTE 2— The 3⁄32-in. [2.4 mm] flat-bottom hole must be flat within 0.002 in. [0.05 mm]. Diameter must be within +0.005 in. [0.13 mm] of the required diameter. Hole axis must be perpendicular to the block and within an angle of 0°, 30 min.

NOTE 3—Hole shall be plugged following checking for ultrasonic response.

in.	[mm]	in.	[mm]
⅛	[3]	1¼	[32]
¼	[6]	1½	[38]
½	[13]	1¾	[44]
¾	[19.0]	2	[50]
1	[25]	10	[254]

FIG. 2 Ultrasonic Standard Reference Block for Dual-Search Unit Calibration

6.2 Test surfaces of castings shall be free of material that will interfere with the ultrasonic examination. They may be as cast, blasted, ground, or machined.

6.3 The ultrasonic examination shall be conducted prior to machining that prevents an effective examination of the casting.

7. Test Conditions

7.1 To assure complete coverage of the specified casting section, each pass of the search unit shall overlap by at least 10 % of the width of the transducer.

7.2 The rate of scanning shall not exceed 6 in./s [150 mm/s].

7.3 The ultrasonic beam shall be introduced perpendicular to the examination surface.

8. Procedure

8.1 Adjust the instrument controls to position the first back reflection for the thickness to be tested at least one half of the distance across the instrument screen.

8.2 Using the set of reference blocks spanning the thickness of the casting being inspected and overlays or electronic markers, note the flat-bottom hole indication height for each of the applicable blocks on the instrument screen. Draw a curve through these marks on the screen or on suitable graph paper. The maximum signal amplitude for the test blocks used shall peak at approximately three-fourths of the screen height above the sweep by use of the attenuator. This curve shall be referred to as the 100 % distance amplitude correction (DAC) curve. If the attenuation of ultrasound in the casting thickness being examined is such that the system's dynamic range is exceeded, segmented DAC curves are permitted.

8.3 The casting examination surface will normally be rougher than that of the test blocks; consequently, employ a transfer mechanism to provide approximate compensation. In order to accomplish this, first select a region of the casting that has parallel walls and a surface condition representative of the rest of the casting as a transfer point. Next, select the test block whose overall length, *C* (Fig. 1), most closely matches the reflection amplitude through the block length. Place the search unit on the casting at the transfer point and adjust the instrument gain until the back reflection amplitude through the casting matches that through the test block. Using this transfer technique, the examination sensitivity in the casting may be expected to be within ±30 % or less of that given by the test blocks.

8.4 Do not change those instrument controls and the test frequency set during calibration, except the attenuator, or calibrated gain control, during acceptance examination of a given thickness of the casting. Make a periodic calibration during the inspection by checking the amplitude of response from the ¼-in. [6.4-mm] diameter flat-bottom hole in the test block utilized for the transfer.

NOTE 2—The attenuator or calibrated gain control may be used to change the signal amplitude during examination to permit small amplitude signals to be more readily detected. Signal evaluation is made by returning the attenuator or calibrated gain control to its original setting.

8.5 During examination of areas of the casting having parallel walls, recheck areas showing 75 % or greater loss of back reflection to determine whether loss of back reflection is due to poor contact, insufficient couplant, misoriented discontinuity, etc. If the reason for loss of back reflection is not evident, consider the area questionable and further investigate.

9. Report

9.1 The manufacturer's report of final ultrasonic examination shall contain the following data and shall be furnished to the purchaser:

9.1.1 The total number, location, amplitude, and area when possible to delineate boundaries by monitoring the movement of the center of the search unit of all indications equal to or greater than 100 % of the DAC,

9.1.2 Questionable areas from 8.5 that, upon further investigation, are determined to be caused by discontinuities,

9.1.3 The examination frequency, type of instrument, types of search units employed, couplant, manufacturer's identifying numbers, purchaser's order number, and data and authorized signature, and

9.1.4 A sketch showing the physical outline of the casting, including dimensions of all areas not inspected due to geometric configuration, with the location and sizes of all indications in accordance with 9.1.1 and 9.1.2.

10. Acceptance Standards

10.1 This practice is intended for application to castings with a wide variety of sizes, shapes, compositions, melting processes, foundry practices, and applications. Therefore, it is impractical to specify an ultrasonic quality level that would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual castings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in production of the particular type of casting.

10.2 Acceptance quality levels shall be established between the purchaser and the manufacturer on the basis of one or more of the following criteria:

10.2.1 No indication equal to or greater than the DAC over an area specified for the applicable quality level of Table 2.

10.2.2 No reduction of back reflection of 75 % or greater that has been determined to be caused by a discontinuity over an area specified for the applicable quality level of Table 2.

10.2.3 Indications producing a continuous response equal to or greater than the DAC with a dimension exceeding the maximum length shown for the applicable quality level shall be unacceptable.

10.2.4 Other criteria agreed upon between the purchaser and the manufacturer.

10.3 Other means may be used to establish the validity of a rejection based on ultrasonic inspection.

NOTE 3—The areas for the ultrasonic quality levels in Table 2 of Practice A609/A 609M refer to the surface area on the casting over which a continuous indication exceeding the DAC is maintained.

NOTE 4—Areas are to be measured from dimensions of the movement of the search unit by outlining locations where the amplitude of the indication is 100 % of the DAC or where the back reflection is reduced by 75 %, using the center of the search unit as a reference point to establish the outline of the indication area.

NOTE 5—In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

TABLE 2 Rejection Level

NOTE 1—The areas in the table refer to the surface area on the casting over which a continuous indication exceeding the amplitude reference line or a continuous loss of back reflection of 75 % or greater is maintained.

NOTE 2— Areas shall be measured from the center of the search unit.

NOTE 3—In certain castings, because of very long test distances or curvature of the test surface, the casting surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases a graphic plot that incorporates a consideration of beam spread should be used for realistic evaluation of the discontinuity.

Ultrasonic Testing Quality Level	Area, in.^{2} [cm^2] (see 10.2.1 and 10.2.2)	Length, max, in. [mm]
1	0.8 [5]	1.5 [40]
2	1.5 [10]	2.2 [55]
3	3 [20]	3.0 [75]
4	5 [30]	3.9 [100]
5	8 [50]	4.8 [120]
6	12 [80]	6.0 [150]
7	16 [100]	6.9 [175]

PROCEDURE B—BACK-WALL REFLECTION CALIBRATION PROCEDURE

11. Apparatus

11.1 Apparatus shall be kept on a regular six month maintenance cycle during which, as a minimum requirement, the vertical and horizontal linearities, sensitivity, and resolution shall be established in accordance with the requirements of Practice E317.

11.2 *Search Units*—Ceramic element transducers not exceeding 1.25 in. [32 mm] diameter or 1 in.^{2} [645 mm^2] shall be used.

11.3 *Search Units Facing*—A soft urethane membrane or neoprene sheet, approximately 0.025 in. [0.64 mm] thick, may be used to improve coupling and minimize transducer wear caused by casting surface roughness.

11.4 *Calibration/Testing*—The same system, including the urethane membrane, used for calibration shall be used to inspect the casting.

11.5 *Other Inspections*—Other frequencies and type search units may be used for obtaining additional information and pinpointing of individual indications.

11.6 *Couplant*—A suitable liquid couplant, such as clean SAE 30 motor oil or similar commercial ultrasonic couplant, shall be used to couple the search unit to the test surface. Other couplants may be used when agreed upon between the purchaser and supplier.

11.7 *Reference Standards*—Reference standards in accordance with Fig. 3 shall be used to calibrate the instrument for inspecting machined and cast surfaces. Reference standards shall be flaw free and machined within tolerances indicated.

12. Ultrasonic Instrument

12.1 *Type*—Pulsed ultrasonic reflection instrument capable of generating, receiving, and amplifying frequencies of 0.5 to 5 MHz shall be used for testing.

12.2 *Voltage*—Line voltage shall be suitably regulated by constant voltage equipment and metal housing must be grounded to prevent electric shock.

12.3 *Linearity*—The instrument must provide a linear presentation (within ±5 %) of at least 1.5 in. [40 mm] sweep to peak (S/P).

12.4 *Calibrated Gain Control of Attenuator*—The instrument shall contain a calibrated gain control or signal attenuator (accurate within ±10 %) which will allow indications beyond the linear range of the instrument to be measured.

12.5 *Time-Corrected Gain*—The instrument shall be equipped to compensate for signal decay with distance. A method should be available to equalize signal response at different depths.

13. Personnel Requirements

13.1 Personnel performing ultrasonic examination in accordance with this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard acceptable to both the purchaser and the supplier.

14. Preparation

14.1 *Time of Inspection*—The final ultrasonic acceptance inspection shall be performed after at least an austenitizing heat treatment and preferably after machining. In order to avoid time loss in production, acceptance inspection of cast surfaces may be done prior to machining. Machined surfaces shall be acceptance inspected as soon as possible after machining. Repair welds may be inspected before the postweld heat treatment.

14.2 *Surface Finish:*

14.2.1 *Machined Surfaces*—Machined surfaces subject to ultrasonic inspection shall have a finish that will produce an ultrasonic response equivalent to that obtained from a 250 µin. [6.3 µm] surface. The surface finish shall also permit adequate movement of search units along the surface.

14.2.2 *Casting Surfaces*—Casting surfaces to be ultrasonically inspected shall be suitable for the intended type and quality level (Table 3 and Table 4) of inspection as judged acceptable by a qualified individual as specified in 13.1.

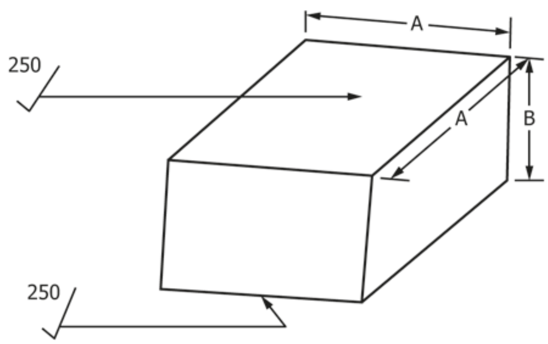
14.2.3 *Surface Condition*—All surfaces to be inspected shall be free of scale, machining or grinding particles, excessive paint thickness, dirt, or other foreign matter that may interfere with the inspection.

14.3 *Position of Casting*—The casting shall be positioned such that the inspector has free access to the back wall for the purpose of verifying change in contour.

15. Calibration

15.1 *Calibration Blocks*—Determine the thickness of the material to be ultrasonically inspected. For material thickness of 3 in. [75 mm] or less, use the series of 3 blocks, ½, 2, 5 in. [13, 50, 125 mm] (Fig. 3, B dimension) for calibration. For a material thickness greater than 3 in., use the series of 3 blocks, 2, 5, 10 in. [50, 125, 250 mm] (Fig. 3, B dimension) for calibration.

15.2 *Calibration of Search Units*—For the thickness of material to be inspected, as determined in 15.1, use the following search units:



Dimensions, in. [mm]		Material
2 [50]	½ [13]	Specification A217/A217M,
2 [50]	2 [50]	Grade WC6 or acoustically similar within ±20 % or 2 dB.
3 [75]	5 [125]	
6 [150]	10 [250]	

Tolerance

All sides to be flat within 0.0002 in. [0.01 mm] and parallel with 0.001 in. [0.03 mm].

FIG. 3 Calibration Blocks

TABLE 3 Acceptance Criteria for Single Isolated Indications

NOTE 1—The area measured by movement of the center of the transducer over the casting surface.

NOTE 2—O = outer wall ⅓, or inner wall ⅓ .
C = mid wall ⅓ .
E = entire wall.

Quality Level	Maximum Non-Linear Indication, Area, in.^{2} [cm^2]	Position of Indication
1	0	E
2	1 [6]	E
3	1 [6]	O
	2 [13]	C
4	3 [19]	E
5	3 [19]	O
	5 [32]	C
6	5 [32]	E
7	5 [32]	O
	7 [45]	C
8	7 [45]	E
9	7 [45]	O
	9 [58]	C
10	9 [58]	E
11	9 [58]	O
	11 [71]	C

TABLE 4 Acceptance Criteria for Clustered Indications

Quality Level	Cumulative Area of Indications, in.^{2} [cm^2]^{A,B}	Minimum Area in Which Indications Must be Dispersed, in.^{2} [cm^2]^C
1	0	0
2–3	2 [13]	36 [232]
4–5	4 [26]	36 [232]
6–7	6 [39]	36 [232]
8–9	8 [52]	36 [232]
10–11	10 [64]	36 [232]

[A] Regardless of wall location, that is midwall ⅓, innermost ⅓, or outermost ⅓ .
[B] Each indication that equals or exceeds the 0.5-in. [13 mm] reference line shall be traced to the position where the indication is equal to 0.25 in. [6 mm]. The area of the location, for the purpose of this evaluation, shall be considered the area that is confined within the outline established by the center of the transducer during tracing of the flaw as required. Whenever no discernible surface tracing is possible, each indication which equals or exceeds the 0.5 in. reference amplitude shall be considered 0.15 in.^{2} [1 cm^2] (three times the area of the ¼ diameter [6 mm] flat bottomed hole to compensate for reflectivity degradation of natural flaw) for the cumulative area estimates.
[C] The indications within a cluster with the cumulative areas traced shall be dispersed in a minimum surface area of the casting equal to 36 in.^{2} [230 cm^2]. If the cumulative areas traced are confined with a smaller area of distribution, the area shall be repair welded to the extent necessary to meet the applicable quality level.

15.2.1 For materials 3 in. [75 mm] or less in thickness, use a 2¼ MHz, ½ in. [13 mm] diameter search unit.

15.2.2 For material greater than 3 in. [75 mm] in thickness, use a 2¼ MHz, 1 in. [25 mm] diameter search unit.

15.3 *Calibration Procedure:*

15.3.1 Set the frequency selector as required. Set the reject control in the "OFF" position.

15.3.2 Position the search unit on the entrant surface of the block that completely encompasses the metal thickness to be inspected (Fig. 3) and adjust the sweep control such that the back reflection signal appears approximately, but not more than three-quarters along the sweep line from the initial pulse signal.

15.3.3 Position the search unit on the entrant surface of the smallest block of the series of 3 blocks selected for calibration and adjust the gain until the back reflection signal height (amplitude) is 1.5 in. [40 mm] sweep to peak (S/P). Draw a line, using overlays or electronic markers, on the instrument screen, parallel to the sweep line, through the peak of the 1.5 in. (S/P) amplitude.

15.3.4 Position the search unit on the entrant surface of the largest block of the series of 3 blocks selected for calibration, and adjust the distance amplitude control to provide a back reflection signal height of 1.5 in. [40 mm] (S/P).

15.3.5 Position the search unit on the entrant surface of the intermediate calibration block of the series of 3 blocks being used for calibration and confirm that the back reflection signal height is approximately 1.5 in. [40 mm] (S/P). If it is not, obtain the best compromise between this block and the largest block of the series of 3 blocks being used for calibration.

15.3.6 Draw a line, using overlays or electronic markers, on the instrument screen parallel to the sweep line at 0.5 in. [13 mm] (S/P) amplitude. This will be the reference line for reporting discontinuity amplitudes.

15.3.7 For tests on *machined surfaces*, position the search unit on a machined surface of casting where the walls are reasonably parallel and adjust the gain of the instrument until the back reflection signal height is 1.5 in. [40 mm] (S/P). Increase the inspection sensitivity by a factor of three times (10 dB gain) with the calibrated attenuator. Surfaces that do not meet the requirements of 14.2.1 shall be inspected as specified in 15.3.8.

15.3.8 For inspections on *cast surfaces*, position the search unit on the casting to be inspected at a location where the walls are reasonably parallel and smooth (inside and outside diameter) and the surface condition is representative of the surface being inspected. Adjust the gain of the instrument until the back reflection signal height is 1.5 in. [40 mm] (S/P). Increase the inspection sensitivity by a factor of six times (16 dB) by use of the calibrated control or attenuator. A significant change in surface finish requires a compensating adjustment to the gain.

15.3.8.1 Rejectable indications on as-cast surfaces may be reevaluated by surface preparation to 250 μin. [6.3 μm] finish or better, and re-inspected in accordance with 15.3.7 of this practice.

15.3.8.2 It should be noted that some instruments are equipped with decibel calibrated gain controls, in which case the decibel required to increase the sensitivity must be added. Other instruments have decibel calibrated attenuators, in which case the required decibel must be removed. Still other instruments do not have calibrated gains or attenuators. They require external attenuators.

16. Scanning

16.1 *Grid Pattern*—The surface of the casting shall be laid out in a 12 by 12 in. [300 by 300 mm] or any similar grid pattern for guidance in scanning. Grid numbers shall be stenciled on the casting for record purposes and for grid area identity. The stenciled grid number shall appear in the upper right hand corner of the grid. When grids are laid out on the casting surface and they encompass different quality levels, each specific area shall be evaluated in accordance with the requirements of the specific quality level designated for that area.

16.2 *Overlap*—Scan over the surface allowing 10 % minimum overlap of the working diameters of the search unit.

16.3 *Inspection Requirements*—All surfaces specified for ultrasonic (UT) shall be completely inspected from both sides, whenever both sides are accessible. The same search unit used for calibration shall be used to inspect the casting.

17. Additional Transducer Evaluation

17.1 Additional information regarding any ultrasonic indication may be obtained through the use of other frequency, type, and size search unit.

18. Acceptance Criteria

18.1 *Rejectable Conditions*—The locations of all indications having amplitudes greater than the 0.5 in. [13 mm] line given in 15.3.6, when amplitude three times (machined surfaces) or six times (cast surfaces) shall be marked on the casting surface. The boundary limits of the indication shall be determined by marking a sufficient number of marks on the casting surfaces where the ultrasonic signal equals one half the reference amplitude, 0.25 in. [6 mm]. To completely delineate the indication, draw a line around the outer boundary of the center of the number of marks to form the indication area. Draw a rectangle or other regular shape through the indication in order to form a polygon from which the area may be easily computed. It is not necessary that the ultrasonic signal exceed the amplitude reference line over the entire area. At some locations within the limits of the indication, the signal may be less than the reference line, but nevertheless still present such that it may be judged as a continuous, signal indication. Rejectable conditions are as follows and when any of the conditions listed below are found, the indications shall be removed and repair welded to the applicable process specification.

18.2 *Linear Indications*—A linear indication is defined as one having a length equal to or greater than three times its width. An amplitude of ½ in. [13 mm], such as would result from tears or stringer type slag inclusion, shall be removed.

18.3 *Non-Linear Indications:*

18.3.1 *Isolated Indications*—Isolated indications shall not exceed the limits of the quality level designated by the customer's purchase order listed in Table 3. An isolated indication may be defined as one for which the distance between it and an adjacent indication is greater than the longest dimension of the larger of the adjacent indications.

18.3.2 *Clustered Indications*—Clustered indications shall be defined as two or more indications that are confined in a 1 in. [25 mm] cube. Clustered indications shall not exceed the limits of the quality level designated by the customer purchase order in Table 4. Where the distance between indications is less than the lowest dimension of the largest indication in the group, the cluster shall be repair welded.

18.3.3 The distance between two clusters must be greater than the lowest dimension of the largest indication in either cluster. If they are not, the cluster having the largest single indication shall be removed.

18.3.4 All indications, regardless of their surface areas as indicated by transducer movement on the casting surface and regardless of the quality level required, shall not have a through wall distance greater than ⅓ *T*, where *T* is the wall thickness in the area containing the indication.

18.3.5 Repair welding of cluster-type indications need only be the extent necessary to meet the applicable quality level for that particular area. All other types of rejectable indications shall be completely removed.

18.3.6 Repair welds of castings shall meet the quality level designated for that particular area of the casting.

18.3.7 Any location that has a 75 % or greater loss in back reflection and exceeds the area of the applicable quality level, and whose indication amplitudes may or may not exceed the 0.5 in. [13 mm] rejection line, shall be rejected unless the reason for the loss in back reflection can be resolved as not being caused by an indication. If gain is added and back echo is achieved without indication percent amplitude exceeding the 0.5 in. [13 mm] rejection line, the area should be accepted.

19. Records

19.1 *Stenciling*—Each casting shall be permanently stenciled to locate inspection zones or grid pattern for ease in locating areas where rejectable indications were observed.

19.2 *Sketch*—A report showing the exact depth and surface location in relation to the stencil numbers shall be made for each rejectable indicator found during each inspection.

19.2.1 The sketch shall also include, but not be limited to, the following:

19.2.1.1 Part identification numbers,
19.2.1.2 Purchase order numbers,
19.2.1.3 Type and size of supplemental transducers used,
19.2.1.4 Name of inspector, and
19.2.1.5 Date of inspection.

20. Product Marking

20.1 Any rejectable areas (those indications exceeding the limits of Section 19) shall be marked on the casting as the inspection progresses. The point of marking shall be the center of the search unit.

21. Keywords

21.1 carbon and low-alloy steel; castings; martensitic stainless steel; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall be applied only when agreed upon between the purchaser and the supplier to achieve an effective examination of a critical casting area that cannot be effectively examined using a longitudinal beam as a result of casting design or possible discontinuity orientation.

S1. Angle Beam Examination of Steel Castings

S1.1 *Equipment:*

S1.1.1 *Search Units*—Angle-beam search units shall produce an angle beam in steel in the range from 30 to 75° inclusive, measured to the perpendicular of the entry surface of the casting being examined. Search units shall have a frequency of 0.5 to 5 MHz.

S1.1.3 *Calibration Blocks*—A set of blocks, as shown in Fig. S1.1, with as cast surface equivalent to SCRATA Comparator A3 and of a thickness comparable to the sections being examined with side-drilled holes at 1/4 *t*, 1/2 *t*, and 3/4 *t* (where *t* = thickness of the block) shall be used to establish an amplitude reference line (ARL).

S1.2 *Calibration of Equipment:*

S1.2.1 Construct the distance amplitude correction curve by utilizing the responses from the side-drilled holes in the basic calibration block for angle beam examination as shown in Fig. S1.1 and Table S1.1.

S1.2.1.1 Resolve and mark the amplitudes of the 1/4 *t* and 1/2 *t* side-drilled holes from the same surface. The side-drilled hole used for the 1/4 *t* amplitude may be used to establish the 3/4 *t* amplitude from the opposite surface or a separate hole may be used.

S1.2.1.2 Connect the 1/4 *t*, 1/2 *t*, and 3/4 *t* amplitudes to establish the applicable DAC.

S1.2.2 The basic calibration blocks shall be made of material that is acoustically similar to the casting being examined.

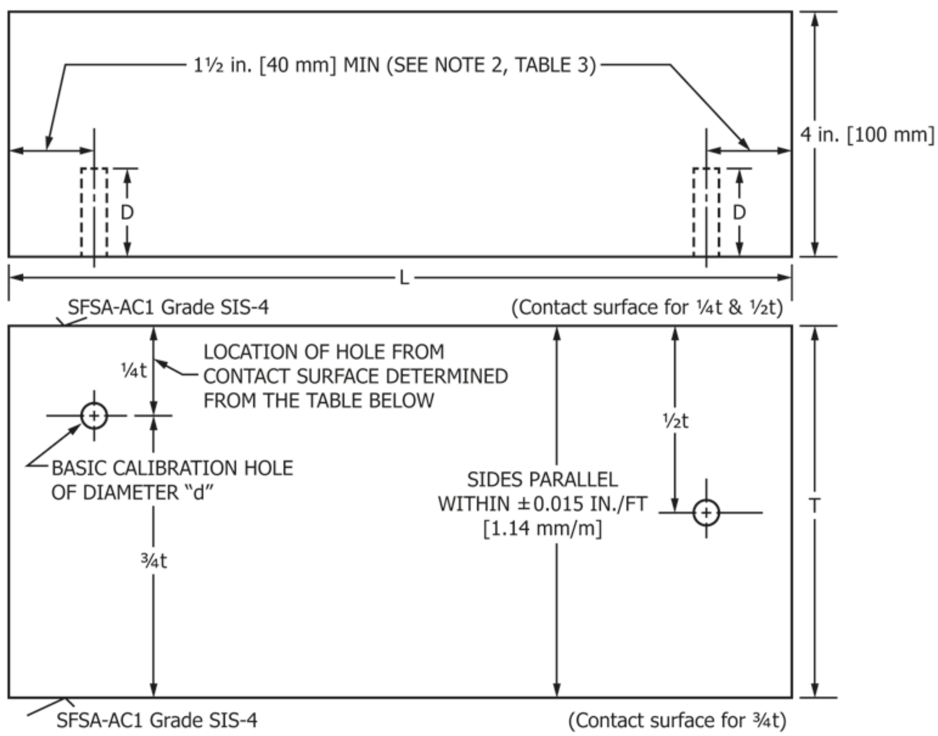
TABLE S1.1 Dimensions of Calibration Blocks for Angle– Beam Examination

NOTE 1—Dimensions of Calibration Blocks for Angle-Beam Examination For each increase in thickness of 2 in. [50 mm], or a fraction thereof, the hole diameter shall increase 1/16 in. [1.6mm].

NOTE 2—For block sizes over 3 in. [75 mm] in thickness, *T*, the distance from the hole to the end of the block shall be 1/2 *T*, min, to prevent coincident reflections from the hole and the corner. Block fabricated with a 2-in. [50-mm] minimum dimension need not be modified if the corner and hole indications can be easily resolved.

Nominal Production Material Thickness (*t*), in. [mm]	Basic Calibration Block Thickness (*T*), in. [mm]	Hole Diameter (*d*), in ± 0.002 [mm ± 0.05]	Minimum Depth (*D*), in. [mm]
Up to 1 [25] incl.	1 [25] or *t*	3/32 [2.4]	1 1/2 [40]
Over 1 to 2 [25–50]	2 [50] or *t*	1/8 [3.2]	1 1/2 [40]
Over 2 to 4 [50–100]	4 [100] or *t*	3/16 [4.8]	1 1/2 [40]
Over 4 to 6 [100–150]	6 [150] or *t*	1/4 [6.3]	1 1/2 [40]
Over 6 to 8 [150–200]	8 [200] or *t*	5/16 [7.9]	1 1/2 [40]
Over 8 to 10 [200–250]	10 [250] or *t*	3/8 [9.5]	1 1/2 [40]
Over 10 [250]	*t*	See Note 1	1 1/2 [40]

S1.2.3 Do not use basic calibration blocks with as cast surface equivalent to SCRATA Comparator A3 to examine castings with surface rougher than SCRATA Comparator A3. Use a machined calibration block for machined surfaces.



L = length of block determined by the angle of search unit and the vee-path used,
T = thickness of basic calibration block (see Table S1.1),
D = depth of side-drilled hole (see Table S1.1),
d = diameter of side-drilled hole (see Table S1.1),
t = nominal production material thickness.

FIG. S1.1 Basic Calibration Block for Angle Beam Examination

S1.2.4 The search unit and all instrument control settings remain unchanged except the attenuator or calibrated gain control.

S1.2.4.1 The attenuator or calibrated gain control may be used to change the signal amplitude during examination to permit small amplitude signals to be more readily detected. Signal evaluation is made by returning the attenuator or calibrated gain control to its original setting.

S1.3 *Data Reporting*—The supplier's report of final ultrasonic examination shall contain the following data:

S1.3.1 The total number, location, amplitude, and area of all indications equal to or greater than 100 % of the distance amplitude curve.

S1.3.2 The examination frequency, type of instrument, type, and size of search units employed, couplant, transfer method, examination operator, supplier's identifying numbers, purchase order number, date, and authorized signature.

S1.3.3 A sketch showing the physical outline of the casting, including dimensions of all areas not examined due to geometric configuration, with the location of all indications in accordance with S1.3.1.

S1.4 *Acceptance Standards*—Acceptance quality levels shall be established between the purchaser and the manufacturer on the basis of one or more of the following criteria:

S1.4.1 No indication equal to or greater than the DAC over an area specified for the applicable quality level of Table 2.

S1.4.2 Other criteria agreed upon between the purchaser and the manufacturer.

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF AUSTENITIC STEEL FORGINGS

SA-745/SA-745M

(Identical with ASTM Specification A745/A745M-15.)

Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings

1. Scope

1.1 This practice covers straight and angle beam contact, pulse-echo ultrasonic examination of austenitic steel forgings produced in accordance with Practice A388/A388M and Specifications A965/A965M and A1049/A1049M.

1.2 Ultrasonic examination of nonmagnetic retaining ring forgings should be made to Practice A531/A531M rather than this practice.

1.3 Supplementary requirements of an optional nature are provided for use at the option of the purchaser. The supplementary requirements shall apply only when specified individually by the purchaser in the purchase order or contract.

1.4 This practice is expressed in inch-pound and SI units; however, unless the purchase order or contract specifies the applicable "M" specification designation (SI units), the inch-pound units shall apply. The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the practice, the SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A388/A388M Practice for Ultrasonic Examination of Steel Forgings

A531/A531M Practice for Ultrasonic Examination of Turbine-Generator Steel Retaining Rings

A788/A788M Specification for Steel Forgings, General Requirements

A965/A965M Specification for Steel Forgings, Austenitic, for Pressure and High Temperature Parts

A1049/A1049M Specification for Stainless Steel Forgings, Ferritic/Austenitic (Duplex), for Pressure Vessels and Related Components

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing

2.2 *American Society for Nondestructive Testing Document:*

SNT-TC-1A Recommended Practice for Nondestructive Personnel Qualification and Certification

3. Ordering Information

3.1 When this practice is to be applied to an inquiry or purchase order, the purchaser shall furnish the following information:

3.1.1 Quality level of examination (see Section 12).

3.1.2 Additional requirements to this practice.

3.1.3 Applicability of supplementary requirements (see Supplementary Requirements section).

3.1.4 Supplementary requirements, if any.

3.2 When specified, the manufacturer shall submit an examination procedure for purchaser approval that shall include, but not be limited to, a sketch of the configuration as presented for ultrasonic examination showing the surfaces to be scanned, scanning directions, notch locations and sizes (if applicable), extent of coverage (if applicable), and an instruction listing calibration and inspection details and stage of manufacture.

4. Apparatus

4.1 *Electronic Apparatus*—A pulse-echo instrument permitting inspection frequencies of 1, 2.25, and 5 MHz is required.

The accuracy of discontinuity amplitude analysis using this practice involves a knowledge of the true operating frequency of the complete inspection system. One of the best ways to obtain the desired accuracy is by use of a tuned pulser and narrow band amplifier of known frequency response, with either a broadband transducer, or a narrow-band tuned transducer of known and matching frequency.

4.1.1 *Apparatus Qualification and Calibration*—Basic qualification of the ultrasonic test instrument shall be performed at intervals not to exceed 12 months or whenever maintenance is performed that affects the equipment function. The date of the last calibration and the date of the next required calibration shall be displayed on the test equipment.

4.1.2 The horizontal linearity shall be checked on a distance calibration bar using the multiple order technique (see Practice E317). The horizontal linearity shall be ±2 % of the metal path.

4.1.3 The accuracy of the linearity shall be checked by ultrasonically verifying the thickness of the component in at least one location beyond the near field of the transducer. If necessary, minor adjustments for differences in the ultrasonic velocities between the calibration bar and the forging shall then be made.

4.2 *Amplifier*—The amplifier and display shall provide linear response within ±2 %, up to 100 % of full screen height.

4.2.1 *Amplifier Calibration*—An amplifier vertical linearity check shall be made prior to performing the test by observing a multiple order pattern from a calibration block using a 2.25 MHz transducer (see Practice E317). The first back reflection shall be set at 100 % of full screen height. The higher order back reflections, 10 % and higher in amplitude, shall also be positioned on the screen and their amplitudes noted. The first back reflection shall be reduced to 50 % and then 25 % of full screen height. The amplitudes of the higher order back reflections shall be noted at each step. The vertical linearity will be considered acceptable if the signal heights of the higher order reflections decrease in proportion to the decrease set for the first back reflection. The maximum acceptable error for the decrease of the higher order reflections is the greater of ±5 % of the expected back reflection height or ±2 % of full screen height.

4.3 *Signal Attenuator*—The instrument shall contain a calibrated gain control or signal attenuator that meets the requirements of Practice E317 (in each case, accurate within ±5 %) that will allow indications beyond the linear range of the instrument to be measured. It is recommended that these controls permit signal adjustments up to 25 to 1 (28 dB).

4.4 *Search Units:*

4.4.1 The maximum nominal active area of 1½ in.^{2} [970 mm^2] with ½-in. [13 mm] minimum to 1⅛-in. [30 mm] maximum dimensions or ¾-in. [20 mm] diameter minimum dimension shall be used for straight-beam scanning.

4.4.2 Angle-beam scanning transducers shall have a nominal active area of ½ to 1 in.^{2} [325 to 650 mm^2]. The search unit used for angle-beam examination shall produce a beam angle of 30 to 70° in the material.

4.4.3 Other search units, including frequencies other than those listed in Section 8, may be used for evaluating and pinpointing indications of discontinuities.

4.5 *Couplant*—A suitable couplant having good wetting characteristics shall be used between the transducer and the examination surface. The same couplant shall be used for calibration and examination.

4.6 *Reference Blocks:*

4.6.1 All ultrasonic standard reference blocks shall be in accordance with the general guidelines of Practice E428. However, absolute conformance to Practice E428 is not mandatory due to the nature of the material covered by this practice.

4.6.2 The reference block grain size, as measured by the relative acoustic penetrability of the reference blocks, should be reasonably similar to the forging under examination. However, it must be recognized that large austenitic forgings vary considerably in acoustic penetrability throughout their volume due to variations in grain size and structure. Reference blocks should be chosen that reasonably approximate the average penetrability of the forging under examination. Supplementary blocks of coarser or finer grain may be used for evaluation of indications as covered in Section 11.

4.6.3 As an alternative method, where practicable, the appropriate size of reference hole (or holes) or notches may be placed in representative areas of the forging for calibration and examination purposes when removed by subsequent machining. When holes or notches are not removed by subsequent machining, the purchaser must approve the location of holes or notches.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Forging Conditions

6.1 Forgings shall be ultrasonically examined after heat treating.

6.2 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

6.3 The surface roughness of scanning surfaces shall not exceed 250 μin. [6 μm] unless otherwise stated in the order or contract where the definition for surface finish is as per Specification A788/A788M.

6.4 The forgings shall be machined to a simple configuration, that is, rectangular or parallel or concentric surfaces where complete volumetric coverage can be obtained.

6.5 In certain cases, such as with contour forged parts, it may be impractical to assure 100 % volumetric coverage. Such forgings shall be examined to the maximum extent possible. A procedure indicating the extent of examination coverage shall be submitted for the purchaser's approval (see 3.2).

7. Procedure

7.1 Perform the ultrasonic examination after heat treatment when the forging is machined to the ultrasonic configuration but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to final contour.

7.2 To ensure complete coverage of the forging volume when scanning, index the search unit with at least 15 % overlap with each pass.

7.3 The scanning rate shall not exceed 6 in. [150 mm]/s.

7.4 Scan all regions of the forging in at least two perpendicular directions to the maximum extent possible.

7.5 Scan disk and disk-type forgings using a straight beam from at least one flat face and radially from the circumference when practicable. For the purposes of this practice, a disk is a cylindrical shape where the diameter dimension exceeds the height dimension. Disk-type forgings made as upset-forged "pancakes" shall be classified as disks for inspection purposes although at the time of inspection, the part may have a center hole, counterturned steps, or other detail configuration.

7.6 Scan cylindrical sections, ring and hollow forgings from the entire external surface (sides or circumference), using the straight-beam technique, and scan the forging in the axial direction to the extent possible. When the length divided by the diameter ratio (slenderness ratio) exceeds 6 to 1 (or axial length exceeds 24 in. [600 mm]), scan axially from both end surfaces to the extent possible. If axial penetration is not possible due to attenuation, angle-beam examination directed axially may be substituted in place of axial straight beam. Examine ring and hollow forgings having an outside-diameter to inside-diameter ratio of less than 2 to 1 and a wall thickness less than 8 in. [200 mm] by angle-beam techniques from the outside diameter or inside diameter, or both, using full node or half-node technique (see 10.1.2 and 10.1.3) as necessary to achieve either 100 % volumetric coverage or the extent of coverage defined by an approved procedure (see 3.2).

8. Examination Frequency

8.1 Perform all ultrasonic examination at the highest frequency practicable (as specified in 8.1.1, 8.1.2, or 8.1.3) that will adequately penetrate the forging thickness and resolve the applicable reference standard. Include in the ultrasonic examination report the examination frequency used. Determine the test frequency at the time of actual examination by the following guidelines:

8.1.1 The nominal test frequency shall be 2.25 MHz. Use of this frequency will generally be restricted due to attenuation.

8.1.2 One megahertz is acceptable and will be the frequency generally applicable.

8.1.3 When necessary, due to attenuation, 0.5-MHz examination frequency may be used. The purchaser may request notification before this lower frequency is employed.

8.1.4 In the event that adequate penetration of certain regions is not possible even at 0.5 MHz, alternative nondestructive examination methods (such as radiography) may be employed to ensure the soundness of the forging by agreement between the purchaser and the manufacturer.

9. Straight-Beam Examination

9.1 *Method of Calibration:*

9.1.1 Perform calibration for straight-beam examination on the flat-bottom hole size determined by the applicable quality level (see Section 12).

9.1.2 Determine the calibration method by the test metal distance involved.

9.1.2.1 Thicknesses up to 6 in. [150 mm] may be examined using either the single-block or the distance-amplitude curve calibration method.

(a) Single-Block Method—Establish the test sensitivity on the reference standard representing the forging thickness. Drill flat-bottom holes normal to the examining surface, to midsection in material up to 1.5 in. [40 mm] in thickness and at least 0.75 in. [20 mm] in depth but no deeper than midsection in thicknesses from 1.5 to 6 in. [40 to 150 mm]. Make evaluations of indications at the estimated discontinuity depth at which they are observed using supplementary reference standards, if necessary.

(b) Distance-Amplitude-Curve Correction Method—Establish the test sensitivity on the reference standard whose metal travel distance represents the greater metal travel distance of the part under examination, within ±1 in. [25 mm].

9.1.2.2 Examine thicknesses from 6 to 24 in. [150 to 600 mm] using the distance-amplitude calibration method. Calibration to ½ thickness test metal distance may be used provided examinations from two opposing surfaces are made.

9.1.2.3 For metal travel distances over 24 in. [600 mm], perform one of the following examinations:

(a) Perform a back-reflection examination from at least one surface to QL-5 (see 12.1.1) or to a purchaser-approved procedure (see 3.2).

(b) On hollow-round forgings with wall thicknesses less than 8 in. [200 mm], perform an axial angle-beam scan in place of the straight-beam scan from the end surfaces. Calibration for this scan may be established on the existing axial notches required for the circumferential scan or on transverse oriented notches installed specifically for axial angle beam.

9.2 *Calibration Procedure*—Over an indication-free area of the forging and with the proper test frequency, adjust the amplitude of the back reflection to the maximum limit of vertical linearity of the instrument. The adjusted instrument sensitivity display shall be the primary calibration reference for both the single-block and multiple-block calibration methods. If, at this gain setting, the amplitude response from the flat-bottom hole in the longest calibration block is not equal to or greater than 0.5 in. [13 mm] sweep-to-peak, adjust the instrument gain further to obtain a 0.5-in. [13 mm] sweep-to-peak minimum response. To complete the distance-amplitude correction curve, determine the remaining points defining the shape of the curve at this adjusted gain setting and mark the curve on the shield of the cathode ray tube or plot on a graph. At least three blocks shall be used with test metal distances of 3 in. [75 mm] ½ *T*, and *T*. However, the distance between any of the test blocks shall be 1½ in. [40 mm] minimum. If indications closer than 3 in. [75 mm] from the initial pulse must be evaluated, an additional block with 1½ in. [40 mm] test metal distance shall be used. This is the fixed reference against which all indications shall be evaluated at the maximum obtainable response at whatever depth the indications are observed. This will constitute an acceptable examination if there are no indications exceeding the acceptance limits. In large forgings, it is expected that a portion of the distance-amplitude curve will be above the vertical linearity limits of the instrument. If an indication appears in this area, readjust the instrument through the use of a calibrated gain control or through recalibration to the initial calibration level to bring the appropriate portion of the presentation on screen for evaluation of that specific area.

NOTE 1—When flat surfaced reference block calibration is used for examination of forgings with surface curvature, compensation for curvature shall be made and the method for curvature correction shall be a matter of agreement between the producer and the purchaser. For diameters 80 in. [2000 mm] and over, no correction factor is required.

10. Angle-Beam Examination

10.1 Ring and hollow round forgings, as defined in 7.6, shall be angle-beam examined from their outer periphery in both circumferential directions employing the following method of calibration:

10.1.1 Notches of 1.25 in. [30 mm] maximum surface length, with the length perpendicular to sound propagation; depth based on quality level (Section12), either rectangular with a width not greater than twice its depth or 60° minimum to 75° maximum included angle, located in the forging so as to produce no interference with each other, shall be used as calibration standards.

10.1.2 Determine the response from the inside and outside diameter calibration notches with the search unit positioned to produce the maximum response from each notch. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch at the greatest test metal distance is at least 0.5 in. [13 mm] sweep-to-peak. Draw a straight line connecting the peaks of the responses obtained from the inside and outside diameter notches. This shall be the primary reference line. This procedure is considered full node calibration.

10.1.3 In the event that a response of at least 0.5 in. [13 mm] sweep-to-peak cannot be obtained from both the inside and outside diameter notches, calibrate from both the outer periphery (the outside diameter surface) and the inside diameter surface. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch in the opposite surface is at least 0.5 in. [13 mm] sweep-to-peak in magnitude. This procedure is considered half-node calibration. Axial angle beam may be substituted for straight beam from the end surfaces, when specified.

NOTE 2—Long cylinders or cylinders with small inside diameters are difficult to examine from the inside diameter surface. Normally, neither inside diameters smaller than 18 in. [450 mm] nor long cylinders exceeding 36 in. [900 mm] in length are scanned from the inside diameter surface.

11. Evaluation of Material

11.1 Coarse-grained austenitic materials frequently display sweep noise, particularly when an examination is performed at high sensitivities. For this reason, it is important to critically scrutinize reportable and rejectable indications to determine whether they result from defects or grain structure. It is desirable to have several sets of calibration blocks with varying degrees of grain coarseness so that the attenuation of the defective area can be reasonably matched with a test block for a more accurate minimum defect size estimation. Due to the normal wide variation in attenuation throughout a given large austenitic forging, it is permissible to evaluate rejectable indications on the basis of alternative calibration blocks that compare more reasonably in attenuation to the defect area. It is also permissible to insert reference holes into representative areas of the forging itself, with the approval of the purchaser, to be used for calibration and evaluation of indications. Loss of back reflection results not only from internal discontinuities but also from coarse or nonuniform grain structures, variations in coupling, nonparallel reflecting surfaces, and other factors that must be considered before concluding that loss of back reflection resulted from discontinuities.

12. Quality Levels for Acceptance

12.1 One of the following quality levels may be specified by the purchaser:

12.1.1 *Straight Beam:*

12.1.1.1 Material producing an indication response whose maximized amplitude equals or exceeds 100 % of the primary reference or distance-amplitude correction curve at the estimated discontinuity depth shall be considered unacceptable.

(a) QL-1—A distance-amplitude curve shall be based upon the amplitude response from No. 8 flat-bottom hole (8⁄64 in. [3 mm]).

(b) QL-2—A distance-amplitude curve shall be based upon the amplitude response from No. 16 flat-bottom hole 16⁄64 in. [6 mm]).

(c) QL-3—A distance-amplitude curve shall be based upon the amplitude response from No. 24 flat-bottom hole 24⁄64 in. [10 mm]).

(d) QL-4—A distance-amplitude curve shall be based upon the amplitude response from No. 32 flat-bottom hole 32⁄64 in. [13 mm]).

(e) QL-5—A back reflection examination shall be performed guaranteeing freedom from complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection of less than 5 % of full screen height shall be considered complete loss of back reflection.

12.1.1.2 The applicable quality level will necessarily vary with test metal distance, purchasers' requirements, and the type and size of forging involved. Large disks, rings, or solid forgings and complex forgings present extraordinary problems and quality level application shall be a matter of agreement between the manufacturer and the purchaser. For general guidance purposes, the following list of test metal distances versus quality level attainable is provided for general information.

(a) QL-1—Generally practical for thicknesses up to 3 in. [75 mm].

(b) QL-2—Generally practical for thicknesses up to 8 in. [200 mm].

(c) QL-3—Generally practical for thicknesses up to 12 in. [300 mm].

(d) QL-4—Generally practical for thicknesses up to 24 in. [600 mm].

(e) QL-5—Frequently practical for thicknesses over 24 in. [600 mm].

12.1.2 *Angle Beam*—Material producing indications with amplitudes equal to or exceeding the primary reference-acceptance line (full node calibration; see 10.1.2) at the estimated discontinuity depth observed shall be considered unacceptable. When examining with only one calibration notch (half node calibration; see 10.1.3), material containing indications of discontinuities equal to or exceeding the notch indication amplitude shall be considered unacceptable.

12.1.2.1 *QA-1* Angle beam reference acceptance shall be based on a notch depth of 3 % of the thickness of the forging at the time of examination.

12.1.2.2 *QA-2* Angle beam reference acceptance line shall be based on a notch depth of the lesser of 5 % of the thickness of the forging at the time of inspection, or ¾ in. [19.05 mm].

13. Reportable Indications

13.1 A record that shows the location and orientation of all indications or groups of indications with amplitudes as defined below shall be submitted to the purchaser for information.

13.1.1 Indications accompanied by a loss of back reflection of 75 % of screen height. Similar loss in back reflection without indications shall be scanned at lower frequencies; if unsuccessful, the area shall be reported as "not inspected."

13.1.2 Indications distinct from the normal noise level and traveling to the left or right on the cathode ray tube with movement of the transducer 1.0 in. [25 mm] or more over the surface of the forging.

13.1.3 Indications equal to or exceeding 50 % of the applicable reference acceptance curve (both straight and angle beam).

14. Keywords

14.1 acceptance criteria; austenitic forgings; contact method; ultrasonic examination

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Angle Beam Calibration Based on Final Thickness

S1.1 The depth of the calibration notch (see 12.1.2) shall be based upon the final ordered thickness of the forging rather than the thickness at the time of inspection.

S2. Surface Finish

S2.1 The surface finish shall not exceed 125 µin. (3.17 µm) where the definition for surface finish is as per Specification A788/A788M.

STANDARD TEST METHOD FOR ULTRASONIC INSPECTION OF ALUMINUM-ALLOY PLATE FOR PRESSURE VESSELS

(**19**) **SB-548**

(Identical with ASTM Specification B548-03(2017).)

Standard Test Method for Ultrasonic Inspection of Aluminum-Alloy Plate for Pressure Vessels

1. Scope

1.1 This test method covers pulse-echo ultrasonic inspection of aluminum-alloy plate of thickness equal to or greater than 0.500 in. (12.7 mm) for use in the fabrication of pressure vessels. The ultrasonic test is employed to detect gross internal discontinuities oriented in a direction parallel to the rolled surface such as cracks, ruptures, and laminations, and to provide assurance that only plate that is free from rejectable discontinuities is accepted for delivery.

1.2 The inspection method and acceptance criteria included in this standard shall be limited to plate of the following aluminum alloys: 1060, 1100, 3003, Alclad 3003, 3004, Alclad 3004, 5050, 5052, 5083, 5086, 5154, 5254, 5454, 5456, 5652, 6061, and Alclad 6061.

1.3 This test method applies only to ultrasonic tests using pulsed longitudinal waves which are transmitted and received by a search unit containing either a single crystal or a combination of electrically interconnected multiple crystals. Ultrasonic tests employing either the through-transmission or the angle-beam techniques are not included.

1.4 This test method shall be used when ultrasonic inspection as prescribed herein is required by the contract, purchase order, or referenced plate specification.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 The following documents of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein:

2.2 *ASTM Standards:*

E114 Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing

E214 Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves (Withdrawn 2007)

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

2.3 *Other Standards:*

ASNT Recommended Practice for Nondestructive Testing Personnel Qualification and Certification—Ultrasonic Testing Method—SNT-TC-1A

3. Summary of Method

3.1 The plate is inspected ultrasonically by scanning one rolled surface with a beam of pulsed longitudinal waves which is oriented in a direction perpendicular to the entry surface of the plate. The ultrasound is transmitted into the plate either by the direct contact, immersion, or liquid-column coupling method. During the scan, an indication representing the first back reflection is observed on the A-scan screen of the test instrument.

3.2 When the test system sensitivity level is appropriately adjusted, a discontinuity is detected during the scan by noting an isolated indication associated with a loss of the first back reflection indication. The apparent size of the discontinuity is determined by measuring the total area in the scanned entry surface of the plate where the isolated indication and the loss of back reflection persist. The estimated discontinuity size and location are then compared with suitable acceptance criteria.

NOTE 1—Additional information describing ultrasonic tests by the direct contact method and by the immersion method is available in Practices E114 and E214.

4. Significance and Use

4.1 A number of factors such as the condition of the entry and back surfaces of the plate, the inclination of the ultrasonic beam with respect to the entry surface, and the performance characteristics of the test system may cause either a reduction of isolated indications or a substantial loss of back reflection and thereby could seriously impair the reliability of the test procedure outlined in this standard.

4.2 Accurate evaluations of discontinuity size also may be limited significantly by variations in beam characteristics which exist in most search units. For this reason, discontinuity size as determined by the test procedure outlined in this method is regarded as "apparent" or "estimated" in recognition of the limited quantitative value of the measurement.

4.3 Because a large number of interacting variables in a test system can adversely influence the results of an ultrasonic test, the actual quantitative effects of detected discontinuities upon the mechanical properties of the inspected plate are difficult to establish. Consequently, this ultrasonic inspection method is not applicable as an exclusive indicator of the ultimate quality and performance of pressure vessels but provides a reliable control of plate quality to avoid failure during the forming process for fabrication of vessels.

5. Apparatus

5.1 *Test Instrument*—Any electronic device that produces pulsed longitudinal waves and displays ultrasonic reflections on an A-scan indicator when used with an appropriate search unit is satisfactory. The instrument shall provide stable, linear amplification of received pulses at a selected test frequency and shall be free from significant interface signal interference at the required sensitivity level.

5.2 *Search Unit*—The search unit recommended for this standard is the flat nonfocusing type, and contains a piezoelectric crystal which generates and receives longitudinal waves at the rated frequency when connected to the test instrument through a suitable coaxial cable. A dual-crystal search unit containing both a transmitting and a receiving crystal in one container may be used provided the test instrument will accommodate two-crystal operation and the resulting pulse-echo test is equivalent to that obtained with a search unit containing a single-crystal.

5.2.1 The total effective area of the crystal or combination of crystals in the search unit used for initial scanning shall not be less than 0.4 in.^{2} (2.6 cm^2) nor greater than 3.0 in.^{2} (19.4 cm^2).

5.2.2 The effective diameter of the round search unit used to evaluate discontinuity size shall not exceed 0.75 in. (19 mm).

NOTE 2—For control purposes, the performance characteristics of the test instrument and search unit may be established in accordance with procedures outlined in Practice E317.

5.3 *Tank*—For tests by the immersion method, any container is satisfactory that will facilitate the accurate, stable positioning of both the search unit and the plate to be inspected.

5.4 *Scanning Apparatus*—During the inspection procedure, the search unit is supported by any one of the following devices. The scanning apparatus shall permit measurement of both the scan distance and the index distance within ±0.1 in. (±2 mm).

5.4.1 *Manipulator and Bridge*—When a manipulator is used in tests by the immersion method, the manipulator shall adequately support a search tube containing a search unit and shall provide fine adjustment of angle within 1° in two vertical planes that are perpendicular to each other. The bridge shall be of sufficient strength to provide rigid support for the manipulator and shall allow smooth, accurate positioning of the search unit. Special search unit supporting fixtures may be used provided they meet the requirements prescribed for a manipulator and bridge.

5.4.2 *Liquid Coupling Nozzle*—For tests by the liquid-column coupling method, the nozzle is usually positioned manually and shall be capable of containing the couplant while rigidly supporting the search unit with its active surface immersed in the couplant. The couplant distance shall be maintained so that the second couplant reflection is to the right of the first back reflection on the instrument cathode ray tube (CRT). The couplant path shall not vary more than ±¼ in. (6.4 mm) during calibration, initial scanning, and discontinuity evaluation. The recommended minimum inside dimension of the nozzle is 1.0 in. (25 mm) greater than the maximum dimension of the crystal surface in the search unit. Provisions also should be included for adjustment of search unit inclination within 1° in two vertical planes that are perpendicular to each other.

NOTE 3—Nozzles containing either sealed or unsealed openings may be used for inspecting plate provided the test results obtained with either device are equivalent to those obtained by the immersion method.

5.4.3 *Contact Scanning Unit*—During tests by the contact method, the search unit usually is supported and positioned manually on the entry surface of the inspected plate. However, special fixtures for contact scanning may be employed provided their use ensures conformance to the requirements in this specification.

5.5 *Couplant*—Clean, deaerated water at room temperature is the recommended couplant for tests either by the immersion method or by the liquid-column coupling technique. Inhibitors or wetting agents or both may be used. For tests by the contact method, the recommended couplant is clean, light-grade oil.

NOTE 4—Other coupling liquids may be employed for inspecting plate provided their use does not adversely affect test results.

6. Personnel Requirements

6.1 The testing operator performing the ultrasonic examination prescribed in this standard shall be qualified and certified to at least a Level I—Ultrasonic Testing in accordance with the ASNT Recommended Practice SNT-TC-1A.

6.2 The required documentation supporting qualification and certification of ultrasonic testing operators shall be established by the certifying agency and shall be available upon request by the purchaser.

7. Condition of Plate

7.1 The entry and back surfaces of the inspected plate shall be sufficiently clean, smooth, and flat to maintain a first back reflection amplitude greater than 50 % of the initial standardization amplitude while scanning an area in the plate that does not contain significant isolated ultrasonic discontinuities.

7.2 The inspected plate shall be at room temperature during the test.

8. Procedure

8.1 *Preferred Method*—The ultrasonic test may be performed by either the liquid column coupling, the direct contact, or the immersion methods. However, the immersion method is preferred.

8.1.1 Maintain the couplant distance so that the second couplant reflection is to the right of the first back reflection on the instrument's A-scan display. The couplant path shall not vary more than ±¼ in. (6.4 mm) during calibration, initial scanning, and discontinuity evaluation.

8.2 *Test Frequency*—When using any of the three methods listed in 8.1, the recommended test frequency is 5.0 MHz. Other test frequencies between 2.0 MHz and 10.0 MHz may be employed when necessary to minimize possible adverse effects of plate thickness, microstructure, and test system characteristics upon test results and thereby maintain a clean, easily interpreted A-scan screen pattern throughout the inspection.

8.3 *Sensitivity Standardization*—Standardize the sensitivity level of the test system operating at the selected frequency by adjusting the instrument gain control to obtain a first back reflection amplitude of 75 ± 5 % of the vertical limit exhibited by the A-scan indicator when the search unit is positioned over an area free from significant discontinuities in the plate to be inspected. During tests by either the immersion method or the liquid column coupling method, adjust the angular alignment of the search unit to obtain a maximum number of back reflections before the final sensitivity level is established.

8.4 *Scanning*—With no further adjustments of the instrument gain controls, locate the search unit over one corner of the plate to be inspected so that the edge of the crystal in the search unit is about 1 in. (25 mm) from either edge of the plate.

8.4.1 Subsequent to checking the angular alignment of the search unit with respect to the rolled entry surface to ensure a maximum first back reflection, proceed to scan the plate continuously by moving the search unit at a constant scanning rate (see 8.6) from the initial starting position to the opposite edge in a direction perpendicular to the predominant rolling direction of the plate.

8.4.2 During the scan, note the occurrence of isolated discontinuity indications and monitor the amplitude of the first back reflection by continuously observing the A-scan indicator screen.

NOTE 5—Auxiliary monitoring devices may be employed in the test system to enhance detection reliability during the scan.

8.5 *Scan Index*—When the initial scan is completed, move the search unit over a predetermined scan index distance in a direction parallel to the predominant rolling direction of the plate and proceed with a second scan along a line parallel to the initial scanning direction while observing the test pattern on the A-scan indicator screen. Calculate the scan index distance as follows:

$$\text{Scan index distance (in.)},\ S_i = 0.8 + 0.7\,D_s \quad (1)$$

$$\text{Scan index distance (mm)},\ S_i = 20 + 0.7\,D_s \quad (2)$$

where:

D_s = actual crystal diameter.

8.5.1 Continue the inspection by constantly observing the test pattern on the A-scan indicator while successively scanning the plate at a constant scanning rate in a direction perpendicular to the predominant rolling direction of the plate and indexing the search unit through the index distance calculated in 8.5.

8.5.2 During the inspection procedure, check the test system sensitivity standardization periodically by noting the amplitude of the first back reflection when the search unit is repositioned over the reference area of the plate and by adjusting the instrument gain control as required to maintain the sensitivity standardization specified previously in 8.3.

8.6 *Scanning Rate*—When the screen pattern on the A-scan indicator is monitored visually by the test operator during the inspection, the scanning rate shall not be greater than 12 in./s (305 mm/s).

NOTE 6—Scanning rates greater than 12 in./s (305 mm/s) may be employed if auxiliary monitoring apparatus is used to maintain adequate detection reliability.

8.7 *Detection of Discontinuities*—When an isolated ultrasonic indication of amplitude greater than 30 % of the A-scan vertical limit is encountered or when the first back reflection indication decreases to an amplitude less than 5 % of the vertical limit at any time during the inspection procedure, stop the scan and angulate the search unit to obtain a maximum isolated indication and to determine that the loss of back reflection is not caused by misalignment of the search unit with respect to the plate.

8.7.1 To ensure that the loss of back reflection is not caused by surface interference, check the condition of both the entry and back surfaces of the plate at the location where a substantial (95 % or greater) loss of back reflection occurs.

8.7.2 Either a maximized isolated ultrasonic indication exhibiting an amplitude greater than 50 % of the amplitude of the initial first back reflection used for standardization, or a substantial loss of the first back reflection indication not attributable to either search unit misalignment or surface interference, is an indication of an internal discontinuity.

NOTE 7—Isolated indications occurring midway between the entry surface indication and the first back reflection may cause a second indication at the location of the first back reflection on the A-scan screen. When this condition is verified by checking the multiple back reflection pattern, a complete loss of the first back reflection can be assumed.

8.8 *Estimation of Discontinuity Size*—Note the location of the search unit where the scan was stopped when either an isolated indication or a loss of back reflection was observed.

8.8.1 Using a search unit containing a crystal of effective diameter no greater than 0.75 in. (19 mm), make an evaluation scan of an entire 6-in. (152-mm) square area which is centered around the point on the plate entry surface where the scan was discontinued. The recommended index distance for this evaluation is as follows: S_i (in. or mm) = 0.7 D_s, where D_s is the actual diameter of the search unit crystal.

8.8.2 To determine the apparent size of the discontinuity, mark each location corresponding to the center of the search unit on the plate entry surface where a 95 ± 5 % loss of first back reflection is observed or where the isolated indication exhibits an amplitude equal to 50 ± 5 % of the amplitude of the initial first back reflection established during the standardization procedure outlined in 8.3.

8.8.3 Continue to mark the location of the search unit at each point where either or both of the discontinuity conditions specified in paragraph 8.8.2 are observed. The entire discontinuity shall be outlined even if it extends beyond the original 6-in. (152-mm) square evaluation scan area.

8.8.4 The estimated discontinuity size is the area defined by the boundary consisting of successive marks as established by this procedure.

NOTE 8—Automatic recording devices may be used to establish the estimated size of a discontinuity provided the recorded results are equivalent to those obtained by the procedure presented in 8.8.

8.9 When the estimated size of a detected discontinuity is determined, return the search unit to the original stopping position and continue the initial scan to complete the inspection.

9. Acceptance Standards

9.1 Upon completing the inspection procedure, measure the longest dimension of each marked area representing a detected discontinuity. Also, when an engineering drawing showing the part to be fabricated from the plate is supplied, compare the locations of the discontinuities with the dimensions on the drawing.

9.2 If the longest dimension of the marked area representing a discontinuity causing a complete loss of back reflection (95 % or greater) exceeds 1.0 in. (25 mm), the discontinuity is considered to be significant and the plate shall be subject to rejection.

9.3 If the length of the marked area representing a discontinuity causing an isolated ultrasonic indication without a complete loss of back reflection (95 % or greater) exceeds 3.0 in. (76 mm), the discontinuity is considered to be significant and the plate shall be subject to rejection.

9.4 If each of two marked areas representing two adjacent discontinuities causing isolated ultrasonic indications without a complete loss of back reflection (95 % or greater) is longer than 1.0 in., and if they are located within 3.0 in. of each other, the proximity between the two discontinuities is considered to be significant, and the plate shall be subject to rejection.

NOTE 9—A template containing a 1.0-in. diameter hole and a 3.0-in. diameter hole is a convenient device for rapidly establishing the significance of discontinuities. If the discontinuities described in 9.2 and 9.3 cannot be totally enclosed within either the 1.0-in. diameter circle or the 3.0-in. diameter circle, respectively, then the plate containing such discontinuities shall be subject to rejection. Similarly, if any portions of two adjacent discontinuities greater than 1.0 in. in length as in accordance with 9.4 appear within the 3.0-in. diameter circle, the plate shall be subject to rejection.

9.5 A plate containing significant discontinuities of rejectable size shall be acceptable if it is established by the purchaser that the discontinuities will be removed from the plate by machining during the subsequent fabrication process.

9.6 Upon specific consent of the purchaser, a plate with significant discontinuities may be accepted if repaired by welding.

10. Report

10.1 When required by the purchaser, a report shall be prepared and shall include the date of test and a list of parameters including the type (model number) of instrument and search unit, the test method, frequency, and the couplant employed for the inspection.

10.2 Preparation of a drawing showing the location of all significant discontinuities in the inspected plate is recommended when the ultimate rejection or acceptance of the plate is to be determined by negotiation between the manufacturer and the purchaser.

10.3 The identification of an acceptable plate is desirable and is recommended. For this purpose, a suitable stamp should be employed to indicate conformance to this ultrasonic standard. The recommended stamp for identifying acceptable plate is shown in Fig. 1.

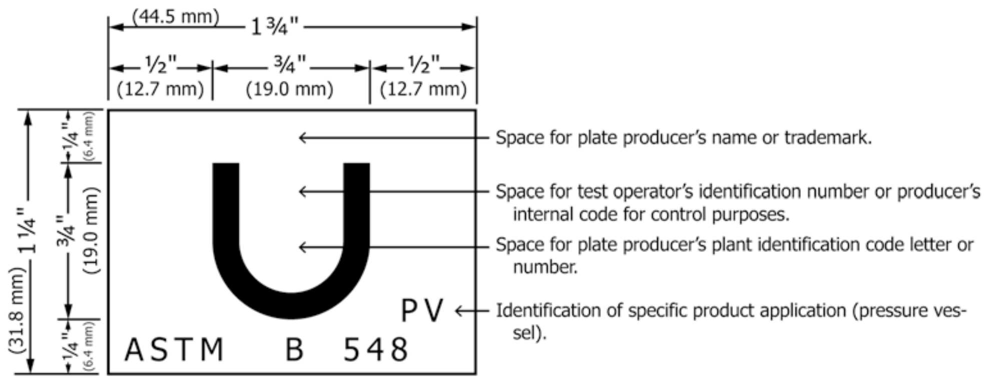


FIG. 1 Stamp for Identifying Acceptable Plate

STANDARD PRACTICE FOR NONDESTRUCTIVE MEASUREMENT OF DRY FILM THICKNESS OF NONMAGNETIC COATINGS APPLIED TO FERROUS METALS AND NONMAGNETIC, NONCONDUCTIVE COATINGS APPLIED TO NON-FERROUS METALS

SD-7091

(Identical with ASTM Specification D7091-13.)

Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

1. Scope

1.1 This practice describes the use of magnetic and eddy current gages for dry film thickness measurement. This practice is intended to supplement the manufacturers' instructions for the manual operation of the gages and is not intended to replace them. It includes definitions of key terms, reference documents, the significance and use of the practice, the advantages and limitations of coating thickness gages, and a description of test specimens. It describes the methods and recommended frequency for verifying the accuracy of gages and for adjusting the equipment and lists the reporting recommendations.

1.2 These procedures are not applicable to coatings that will be readily deformed under the load of the measuring gages/probes, as the gage probe must be placed directly on the coating surface to obtain a reading. Provisions for measuring on soft or tacky coatings are described in 5.7.

1.3 Coating thickness can be measured using a variety of gages. These gages are categorized as "magnetic pull-off" and "electronic." They use a sensing probe or magnet to measure the gap (distance) between the base metal and the probe. This measured distance is displayed as coating thickness by the gages.

1.4 Coating thickness can vary widely across a surface. As a result, obtaining single-point measurements may not accurately represent the actual coating system thickness. SSPC-PA2 prescribes a frequency of coating thickness measurement based on the size of the area coated. A frequency of measurement for coated steel beams (girders) and coated test panels is also provided in the appendices to SSPC-PA 2. The governing specification is responsible for providing the user with the minimum and the maximum coating thickness for each layer, and for the total coating system.

1.5 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products

D823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels

D1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting

2.2 *SSPC Standard:*

SSPC-PA 2 Procedure for Determining Conformance to Dry Coating Thickness Requirements

2.3 *ISO Standard:*

ISO 19840 Paints and varnishes—corrosion protection of steel structures by protective paint systems—Measurement of, and acceptance criteria for, the thickness of dry films on rough surfaces

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *accuracy, n*—the measure of the magnitude of error between the result of a measurement and the true thickness of the item being measured.

3.1.1.1 *Discussion*—An accuracy statement predicts the ability of a coating thickness gage to measure the true thickness of a coating to be measured. Accuracy statements provide the performance capability across the full functional measurement range of the gage. Accuracy statements frequently include a fixed portion that remains constant across the measurement range, plus a variable portion that is related to the measurement result for a particular thickness.

3.1.2 *adjustment (optimization), n*—the physical act of aligning a gage's thickness readings to match those of a known thickness sample (removal of bias), in order to improve the accuracy of the gage on a specific surface or within a specific portion of its measurement range.

3.1.2.1 *Discussion*—An adjustment will affect the outcome of subsequent readings.

3.1.3 *base metal reading (BMR), n*—a measurement obtained on the uncoated substrate using a coating thickness gage.

3.1.3.1 *Discussion*—The BMR is the determined effect of substrate roughness on a coating thickness gage that is caused by the manufacturing process (for example, castings) or surface profile (roughness)-producing operations (for example, power tool cleaning, abrasive blast cleaning, etc.). Non-compensation for the base metal effect can result in an overstatement of the true thickness of the coating.

3.1.4 *calibration, n*—the high-level, controlled and documented process of obtaining measurements on traceable calibration standards over the full operating range of the gage, then making the necessary gage adjustments (as required) to correct any out-of-tolerance conditions.

3.1.4.1 *Discussion*—Calibration of coating thickness gages is performed by the equipment manufacturer, their authorized agent, or by an accredited calibration laboratory in a controlled environment using a documented process. The outcome of the calibration process is to restore/realign the gage to meet/exceed the manufacturer's stated accuracy.

3.1.5 *certification, n*—documentation of the state of condition of the gage, which can (but not required by definition) be accompanied by corrective action (such as adjustment or calibration, or both, or the replacement of components) necessary to correct any out-of-tolerance conditions.

3.1.6 *coating thickness standard, n*—coated or plated metal plates, or uncoated shims of flat sheet, with assigned values traceable to a National Metrology Institution.

3.1.6.1 *Discussion*—In the case of the eddy current principle, the coating and shim material must be non-metallic, whereas in the case of the magnetic induction and the Hall-effect methods the material must be nonmagnetic.

3.1.7 *compensation value, n*—generating a verifiable value, which is deducted from a measured value read from the gage, to correct for any surface conditions (that is, base metal effect).

3.1.8 *dry film thickness, n*—the thickness of a coating (or coating layers) as measured from the surface of the substrate.

3.1.8.1 *Discussion*—If the surface of the substrate is roughened, the dry film thickness is considered the thickness of the coating or coating layers above the peaks of the surface profile.

3.1.9 *ferrous, n*—containing iron.

3.1.9.1 *Discussion*—Describes a magnetic material such as carbon steel. That material may also be known as ferromagnetic.

3.1.10 *gage (gauge), n*—an instrument for measuring quantity, or an instrument for testing.

3.1.10.1 *Discussion*—In this practice, the term "gage" refers to an instrument for quantifying coating thickness.

3.1.11 *manufacturer's specifications, n*—a statement or set of statements that describes the performance characteristics of the gage under a given set of conditions.

3.1.11.1 *Discussion*—Manufacturer's specifications typically include the range of measurement, accuracy statement, operating temperature range, power source, dimensions and weight, and conformance to industry standards.

3.1.12 *measurement (reading), n*—the value obtained when placing the probe of a thickness gage in contact with a surface.

3.1.13 *micrometer (micron), n*—one one-thousandth of a millimeter [0.001 mm]; 25.4 microns = 1 mil.

3.1.14 *mil, n*—a U.S. term referring to the imperial unit of measure of one one-thousandth of an inch [0.001 in.] referred to elsewhere in the world as "one thou;" 1 mil = 25.4 microns.

3.1.15 *nonconductive, n*—a material that is unable to conduct electricity.

3.1.16 *non-ferrous metal, n*—a nonmagnetic metal or metal alloy (for example, copper, aluminum or brass).

3.1.17 *reference sample, n*—a coated or uncoated metal specimen of the same material and geometry as the specific measuring application used to adjust and/or verify the accuracy of a coating thickness measuring gage for a specific project.

3.1.17.1 *Discussion*—A coated reference sample may or may not have thickness values traceable to a National Metrology Institution. However, the reference sample should be marked with the stated value and the degree of accuracy. The coating thickness of the sample should be close to the user's coating thickness measurement requirement.

3.1.18 *shims (foils), n*—strips of flat sheet, with the thickness stated or referenced in some form, which can be used to adjust a Type 2 coating thickness gage in the intended range of use over the surface of the representative substrate material.

3.1.18.1 *Discussion*—Other uses with Type 2 gages include: placement over soft coatings to obtain thickness measurements without the gage probe depressing the coating film, and verification of gage operation.

3.1.19 *substrate, n*—the base material, the type of surface, or the component that is being coated.

NOTE 1—This practice addresses only metal substrates.

3.1.20 *surface profile, n*—surface texture generated during the manufacturing process (for example, casting), or the peak-to-valley depth generated by some power tools and by abrasive blast cleaning operations.

3.1.21 *Type 1 (pull-off) gage, n*—a magnetic pull-off instrument that measures the dry film thickness of nonmagnetic coatings over a ferrous metal base.

3.1.21.1 *Discussion*—For Type 1 gages, a probe containing a permanent magnet is brought into direct contact with the coated surface. The force necessary to pull the magnet from the surface is measured and interpreted as the coating thickness value on a scale or display on the gage. Less force is required to remove the magnet from a thick coating. The scale is nonlinear.

3.1.22 *Type 2 (electronic) gage, n*—an electronic instrument that uses electronic circuitry and (but not limited to) the magnetic induction, Hall-effect or eddy current principles, or a combination of a magnetic and eddy current principles, to convert a reference signal into a coating thickness reading.

3.1.22.1 *Discussion*—The probe of a Type 2 gage remains on the surface during the measurement process.

3.1.23 *verification of accuracy, n*—obtaining measurements on coating thickness standards, comprising of at least one thickness value close to the expected coating thickness, prior to gage use for the purpose of determining the ability of the coating thickness gage to produce thickness results within the gage manufacturer's stated accuracy.

4. Significance and Use

4.1 This practice describes three operational steps necessary to ensure accurate coating thickness measurement: calibration, verification and adjustment of coating thickness measuring gages, as well as proper methods for obtaining coating thickness measurements on both ferrous and non-ferrous metal substrates.

4.2 Many specifications for commercial and industrial coatings projects stipulate a minimum and a maximum dry film thickness for each layer in a coating system. Additionally, most manufacturers of high performance coatings will warranty coating systems based upon, in part, achieving the proper thickness of each layer and the total coating system. Even if a project specification is not provided, the coating manufacturer's recommendations published on product data sheets can become the governing document(s). Equipment manufacturers produce nondestructive coating thickness testing gages that are used to measure the cumulative or individual thickness of the coating layers, after they are dry. The manufacturers provide information for the adjustment and use of these gages, normally in the form of operating instructions. The user of this equipment must be knowledgeable in the proper operation of these devices, including methods for verifying the accuracy of the equipment prior to, during and after use as well as measurement procedures.

5. Principles, Advantages, and Limitations of Gages

5.1 Type 1 magnetic pull-off gages employ an attraction principle and a static (non-time varying) magnetic field. These mechanical instruments measure the force required to pull a permanent magnet from a coated ferrous metal substrate. The magnetic force of attraction to the steel substrate beneath the coating is opposed by a spring or coil. Tension is applied to the spring/coil until the magnetic attraction to the steel is overcome. The gage must be placed directly on the coated surface to obtain a measurement. The force holding the permanent magnet to the ferrous base is inversely proportional to the thickness of the coating layer(s) between the magnet and the ferrous substrate. For example, a thin coating applied to a ferrous substrate will require greater spring tension to pull the magnet off than will a thicker coating, since the magnet is closer to the ferrous substrate with the thinner coating. This inverse relationship is reflected on the nonlinear gage scale. Most Type 1 magnetic pull-off gages do not require a power source (for example, batteries). The manufacturer's stated accuracy is typically 5 to 10 % of the reading.

5.2 Type 1 magnetic pull-off gages are susceptible to vibrations, which may cause the magnet to release from the coated substrate prematurely, yielding a false high value. The manually operated gages may be susceptible to human error caused by inadvertently turning the dial wheel past the point at which the magnet pulls from the surface, yielding a false low measurement. Type 1 gages should not be used on soft or tacky coatings, as the magnet may adhere to the coating causing false low measurements, or coating materials may dry on the magnet causing false high measurements. The exposed magnet may attract metal filings, which can contaminate the magnet and cause false high measurements. Type 1 gages cannot be used to measure the thickness of coatings applied to non-ferrous metal substrates. The manufacturer's specifications will contain a temperature operating range. Use of the gage outside of this range may generate false coating thickness measurements and may damage the instrument.

5.3 Type 2 gages are instruments that employ a measuring probe and the magnetic induction, Hall-effect or eddy current measurement principle in conjunction with electronic microprocessors to produce a coating thickness measurement. The gage probe must be placed directly (in a perpendicular position) on the coated surface to obtain a measurement.

5.3.1 For gages measuring on ferrous substrates, the magnetic induction or Hall-effect principles are used to measure a change in magnetic field strength within their probes to produce a coating thickness measurement. These gages determine the effect on the magnetic field generated by the probe due to the proximity of the substrate.

5.3.2 For gages measuring on non-ferrous metals, the gage probe coil is energized by alternating current that induces eddy currents in the metal substrate. The eddy currents in turn create a secondary magnetic field within the substrate. The characteristics of this secondary field are dependent upon the distance between the probe and the basis metal. This distance (gap) is measured by the probe and shown on the gage display as the thickness (microns or mils) of the intervening coating. Note that gages/probes for measuring coating thickness on non-ferrous metals should not be used to measure coating thickness on ferrous surfaces, even though a reading may be displayed.

5.4 Type 2 gages are available with integral or separate (wired or wireless) probes, and they can be used to measure coating thickness on ferrous or non-ferrous metal substrates, or both, depending on the probes supported by the particular gage platform. The thickness of the coating is displayed digitally. In general, access to tight areas is easier with Type 2 gages, especially those equipped with separate or remote probes. Type 2 gages are available with memory, measurement batching, statistical analysis packages and data download/print-out. The manufacturer's stated accuracy is typically 1 to 3 % of the reading.

5.5 Instruments using either a magnetic or eddy current principle measure total film thickness only. In multi-layer coating systems the thickness of each layer must be measured after it is applied. Even then, the thickness of the measured layer is the cumulative thickness of that layer and all layers beneath it, down to the base metal.

5.5.1 Some instruments employ both principles and may be capable of measuring the individual thickness of two layers such as paint over zinc (duplex coating) on steel.

5.6 Most electronic coating thickness measuring gages can be verified for accuracy using coating thickness standards. Gages that cannot be adjusted by the user should be returned to the manufacturer or their authorized agent for calibration if the readings obtained on the coating thickness standards are outside of the combined accuracy of the standard and the manufacturer's stated gage accuracy.

5.6.1 Gage operation should be verified on a prepared, uncoated substrate having the same composition, shape and surface profile to which the coating will be applied to, for the intended range of use. If necessary, the gage should be adjusted as described in 7.4.

5.7 Type 2 gages should not be used directly on soft or tacky coatings, unless expressly designed for this application, as the pressure on the probe can indent the coating yielding false low measurements, or coating materials may contaminate the probe yielding false high measurements. A shim of known thickness can be placed on top of the soft/tacky coating film and a measurement of the coating thickness obtained by subtracting the shim thickness from the total measurement of the shim and the coating. Note that some Type 2 gages can be programmed to automatically deduct the shim thickness (known as "zero offset"). Type 2 gages may be sensitive (to some degree) to substrate effects including, but not limited to, edges, corners and holes in the substrate, as well as substrate thickness. The manufacturer's specifications will contain a temperature operating range. Use of the gage or the probe outside of this range may generate false coating thickness measurements and may damage the instrument.

5.8 Coating thickness measurement accuracy can also be affected by, but is not limited to, the factors listed below. Consult the instrument manufacturer for details on the specific effects of these factors and how they are addressed by the instrument.

5.8.1 *Curvature*—The influence of curvature varies considerably with the make and type of instrument but often becomes more pronounced as the radius of curvature decreases.

5.8.2 *Foreign Particles*—Instruments of all types must make physical contact with the test surface and are, therefore, sensitive to foreign material that prevents intimate contact between probe and coating surface. Both the test surface and instrument probe should be kept free of foreign material.

5.8.3 *Stray Magnetic Fields*—Strong stray magnetic fields, such as are produced by various types of electrical equipment, can seriously interfere with the operation of instruments based on magnetic principles.

5.8.4 *Metal-filled Coatings*—Instruments may produce erroneous results depending on the type and amount of metal in the coating film.

5.8.5 *Electrical Properties of the Basis Metal*—Eddy current measurements are affected by the electrical conductivity of the base metal, which itself is often affected by heat treatments. Instruments and probes are available that compensate for base material influence thus automatically avoiding such errors.

5.8.6 *Pressure*—The pressure with which the probe is applied to the test specimen affects the instrument readings and should therefore be kept constant.

6. Test Specimen

6.1 The test specimen can be the coated structure or component/part on which the thickness is to be evaluated, or can be test panels of similar surface profile, shape, thickness, composition and magnetic properties on which it is desired to measure the coating thickness.

NOTE 2—Applicable test panel description and surface preparation methods are given in Practices D609 and D1730.

NOTE 3—Coatings should be applied in accordance with Practices D823 or as agreed upon between the contracting parties.

NOTE 4—Test panels may be fabricated from thin gage materials and special consideration for gage adjustment may be required.

7. Frequency and Methods for Verifying the Accuracy and for Adjusting a Coating Thickness Gage

7.1 Three operational steps are necessary to ensure accurate coating thickness measurement: calibration, verification of accuracy, and adjustment.

7.2 *Calibration*—Calibration of coating thickness gages is performed by the equipment manufacturer, their authorized agent, or by an accredited calibration laboratory in a controlled environment using a documented process. A Certificate of Calibration showing traceability to a National Metrology Institute can be issued. There is no standard time interval for re-calibration, nor is one absolutely required, but a calibration interval can be established based on experience and the work environment. A one-year calibration interval is a typical frequency suggested by many gage manufacturers.

7.3 *Verification of Accuracy*—Before use, each instrument's calibration accuracy shall be verified by the user in accordance with the instructions of the manufacturer, employing suitable coating thickness standards and, if necessary, any deficiencies found shall be corrected. The gage should be verified for accuracy in the intended range of use. Also, the probe should be examined for cleanliness before verifying the accuracy and before obtaining coating thickness measurements.

7.3.1 If the gage readings obtained during verification are outside the combined accuracy of the coating thickness standard and the manufacturer's stated gage accuracy, the gage should be returned to the manufacturer or their authorized agent for repair and calibration.

7.3.2 For example, if the gage accuracy is ±5 % and the standards accuracy is ±5 %, then the combined accuracy of the gage and the standard will be ±7 % as given by the sum of the squares formula:

$$\sqrt{5^2+5^2} = 7.071 \text{ or approximately } 7\ \% \quad (1)$$

7.3.2.1 For the gage to be in agreement with the standard, the average thickness measured by the gage must be within ±7 % of the standard's thickness. If the average thickness measured on a 254 µm [10 mil] standard is between 236 µm [9.3 mils] and 272 µm [10.7 mils], the gage is properly adjusted. The minimum value of 236 µm is calculated as 254 µm minus 7 % of 254 µm [9.3 mils is 10 mils minus 7 % of 10 mils]; the maximum of 272 µm is 254 µm plus 7 % of 254 µm [10.7 mils is 10 mils plus 7 % of 10 mils]. Otherwise the accuracy of the gage is suspect.

7.3.3 Unless explicitly permitted by the gage manufacturer, shims of plastic or of non-magnetic metals which are acceptable for verifying the accuracy of Type 2 (electronic) gages are not used for verifying the accuracy of Type 1 (pull-off) gages.

7.3.4 Since Type 1 gages are verified for accuracy using smooth-surfaced standards (or using a smooth zero plate), a compensation value may be required if the substrate to be coated is different from the standard (such as, but not limited to, curvature or composition) or roughened from the manufacturing process (for example, casting) or from abrasive blast cleaning. This is known as a Base Metal Reading or BMR. The BMR is the effect of substrate (for example, surface profile) on a coating thickness gage. The user obtains a minimum of ten (10) readings on the prepared, uncoated substrate. The arithmetic mean of these values becomes the Base Metal Reading. The BMR is deducted from the coating thickness values in order to report the thickness of the coating layer(s) over the surface profile.

7.4 *Adjustment*—Many instruments can be adjusted by the user in order to improve their accuracy on a specific surface or within a specific portion of its measurement range. In most instances it should only be necessary to check zero on the uncoated substrate and begin measuring. However the effects of properties of the substrate (composition, magnetic properties, shape, surface profile, edge effects) and coating (composition, mass, surface texture), as well as ambient and surface temperatures, may require adjustments to be made to the instrument. Follow the manufacturer's instructions.

7.4.1 The user should never adjust Type 1 coating thickness gages.

7.4.2 Most Type 2 gages can be adjusted using either a one-point or a two-point procedure.

7.4.2.1 *Adjustment of Type 2 Gages Using a One-Point Procedure*—A one-point adjustment involves fixing the instrument's calibration curve at one point after taking several readings on a single coating thickness standard or reference sample. Adjusting to zero on an uncoated sample of the test specimen is the simplest form of a one-point adjustment. If the user elects to perform a one-point adjustment procedure to a known thickness, a reference sample representing the target range of gage use should be selected and a measurement taken. No adjustment is necessary if the value displayed by the gage is within the combined accuracy of the reference sample and the manufacturer's stated gage accuracy (see 7.3.2). If the gage reading is outside of the combined accuracy of reference sample and the manufacturer's stated gage accuracy, then the user should carefully follow the gage manufacturer's instructions for proper adjustment, as the actual step-by-step procedures vary widely.

7.4.2.2 *Adjustment of Type 2 Gages Using a Two-Point Procedure*—A two-point adjustment fixes the instrument's calibration curve at two known thicknesses. Coated reference samples or shims placed over the uncoated substrate or over an uncoated reference sample may be used. The two thicknesses selected must be on either side of the expected coating thickness. The user should carefully follow the gage manufacturer's instructions for performing a two-point adjustment, as the actual step-by-step procedures vary widely.

NOTE 5—ISO 19840 describes the use of a profile correction value when access to the uncoated substrate is not available.

8. Frequency for Measurement of Coating Thickness

8.1 Thickness is determined by placing the probe of the instrument onto the surface of the coated metal material and obtaining the thickness measurement in accordance with the manufacturer's instructions.

8.2 The thickness of a coating or a coating system can vary from area to area on a structure or part. Accordingly, it is recommended that a number of measurements be obtained and the arithmetic mean calculated to determine the high, low and average coating thickness in a given area. SSPC-PA 2 prescribes a frequency of coating thickness measurement based on the size of the area coated.

8.3 For small parts or components, the number of coating thickness measurements is typically based on the criticality of the application, and should be as agreed upon between the purchaser and seller.

8.4 For mass quantities of manufactured products, the frequency of coating thickness measurement is dictated by the volume produced and should be based on statistical process control (SPC) calculations for sample size selection.

9. Report

9.1 The following items should be reported:

9.1.1 Type of instrument used including manufacturer, model number, serial number, and date of calibration,

9.1.2 Type of coating thickness standard and/or reference standard together with the method used for accuracy verification and/or any adjustment,

9.1.3 Size and description of test specimen,

9.1.4 Base Metal Reading (if appropriate),

9.1.5 The value of each measurement (if appropriate),

9.1.6 Operator identification, and

9.1.7 Date of the inspection.

10. Keywords

10.1 coatings; coating thickness; dry film thickness; eddy current thickness gages; magnetic gages; magnetic method; nondestructive thickness; paint thickness; thickness testing

APPENDIX

(Nonmandatory Information)

X1. PRECAUTIONS REGARDING VERIFICATION OF GAGE ACCURACY

X1.1 When selecting shims to verify the accuracy of Type 2 coating thickness gages, it is necessary to be aware of additional characteristics that can affect the measured values. These factors include, but are not limited to:

X1.1.1 Permanent creases in the shim due to folding,

X1.1.2 Air entrapment between the shim and substrate,

X1.1.3 Distortion due to environmental conditions, such as temperature, and

X1.1.4 Shim thickness inconsistency (due to the pressure of the probe tip) that may be a permanent "dimple" in the shim.

X1.2 Even with these factors, in many applications, verification of gage accuracy using shims directly on the sample to be measured can be more appropriate than using plated or coated standards. Some gage manufacturers produce certified shims.

X1.3 Independent of what standard is employed, they should be periodically verified to ensure the assigned value is correct. Even coated metal plates can wear or be damaged to an extent that gage readings are affected.

X1.4 When verifying the accuracy of magnetic gages on coated steel standards it is important to be aware of the effect of the coating on some types of magnetic gages. For best accuracy when measuring with magnetic induction principle gages, consider the following:

X1.4.1 Verify gage accuracy on metal plated (conductive coating) standards when measuring conductive coatings (for example, chrome and zinc); verify gage accuracy on epoxy coated (non-conductive) standards when measuring non-conductive coatings (for example, paint).

X1.4.2 Gages that use the Hall-effect principle are not affected by the conductive nature of the coating.

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STANDARD PRACTICE FOR ULTRASONIC TESTING OF METAL PIPE AND TUBING

SE-213

(Identical with ASTM Specification E213-14e1.)

Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing

1. Scope

1.1 This practice covers a procedure for detecting discontinuities in metal pipe and tubing during a volumetric examination using ultrasonic methods. Specific techniques of the ultrasonic method to which this practice applies include pulse-reflection techniques, both contact and non-contact (for example, as described in Guide E1774), and angle beam immersion techniques. Artificial reflectors consisting of longitudinal, and, when specified by the using party or parties, transverse reference notches placed on the surfaces of a reference standard are employed as the primary means of standardizing the ultrasonic system.

1.2 This practice is intended for use with tubular products having outside diameters approximately ½ in. (12.7 mm) and larger, provided that the examination parameters comply with and satisfy the requirements of Section 12. These procedures have been successful with smaller sizes. These may be specified upon contractual agreement between the using parties. These procedures are intended to ensure that proper beam angles and beam shapes are used to provide full volume coverage of pipes and tubes, including those with low ratios of outside diameter-to-wall thickness, and to avoid spurious signal responses when examining small-diameter, thin-wall tubes.

1.3 The procedure in Annex A1 is applicable to pipe and tubing used in nuclear and other special and safety applications. The procedure in Annex A2 may be used to determine the helical scan pitch.

1.4 This practice does not establish acceptance criteria; they must be specified by the using party or parties.

1.5 The values stated in inch-pound units are to be regarded as standard. The SI equivalents are in parentheses and may be approximate.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

E1774 Guide for Electromagnetic Acoustic Transducers (EMATs)

E1816 Practice for Ultrasonic Testing Using Electromagnetic Acoustic Transducer (EMAT) Techniques

2.2 *ASNT Documents:*

Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *ISO Standards:*

ISO 9712 Non-destructive Testing— Qualification and Certification of NDT Personnel

2.4 *Aerospace Industries Association Document:*

NAS 410 Certification and Qualification of Nondestructive Testing Personnel

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E1316.

4. Summary of Practice

4.1 A pulsed ultrasonic angle beam by means of non-contact, surface contact or immersion method shall be used. Fig. 1 illustrates the characteristic ultrasonic angle beam entry into the wall of a pipe or tube in the circumferential direction to detect longitudinal discontinuities using a single search unit. Fig. 2 illustrates the characteristic angle beam ultrasound entry into the wall of a pipe or tube in the axial direction to search for transverse discontinuities using a single search unit.

NOTE 1—The immersion method may include tanks, wheel search units, or systems that use streams or columns of liquid to couple the ultrasonic energy from the search unit to the material.

4.2 To ensure detection of discontinuities that may not provide a favorable response from one side, scanning shall be performed in both circumferential directions for longitudinal discontinuities and when an axial scan is specified by the using party or parties, in both axial directions for transverse discontinuities.

4.3 For efficient examination of large quantities of material, multiple search units and instruments may be used simultaneously to perform scanning in the required directions. Multiple search units may be employed for "interlaced" scanning in each required direction to enable higher examination rates to be achieved through higher allowable scan index or "pitch."

5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for detecting and locating significant discontinuities such as pits, voids, inclusions, cracks, splits, etc., by the ultrasonic pulse-reflection method.

6. Basis of Application

6.1 The following are items that must be decided upon by the using party or parties.

6.1.1 Size and type of pipe or tubing to be examined,

6.1.2 Additional scanning for transverse discontinuities,

6.1.3 Items that affect examination coverage may also be specified such as scan overlap, pulse density and maximum search unit size.

6.1.4 The stage(s) in the manufacturing process at which the material will be examined,

6.1.5 Surface condition,

6.1.6 Maximum time interval between equipment standardization checks, if different from that described in 13.2 and the tolerance to be applied to a standardization check,

6.1.7 Type, dimensions, location, method of manufacture, and number of artificial reflectors to be placed on the reference standard,

6.1.8 Method(s) for measuring dimensions of artificial reflectors and tolerance limits if different than specified in Section 11,

6.1.9 Criteria for reportable and rejectable indications (acceptance criteria),

6.1.10 Reexamination of repaired/reworked items, if required or permitted, shall be specified in the contractual agreement.

6.1.11 Requirements for permanent records of the response from each tube, if applicable,

6.1.12 Contents of examination report,

6.1.13 Operator qualifications and certification, if required,

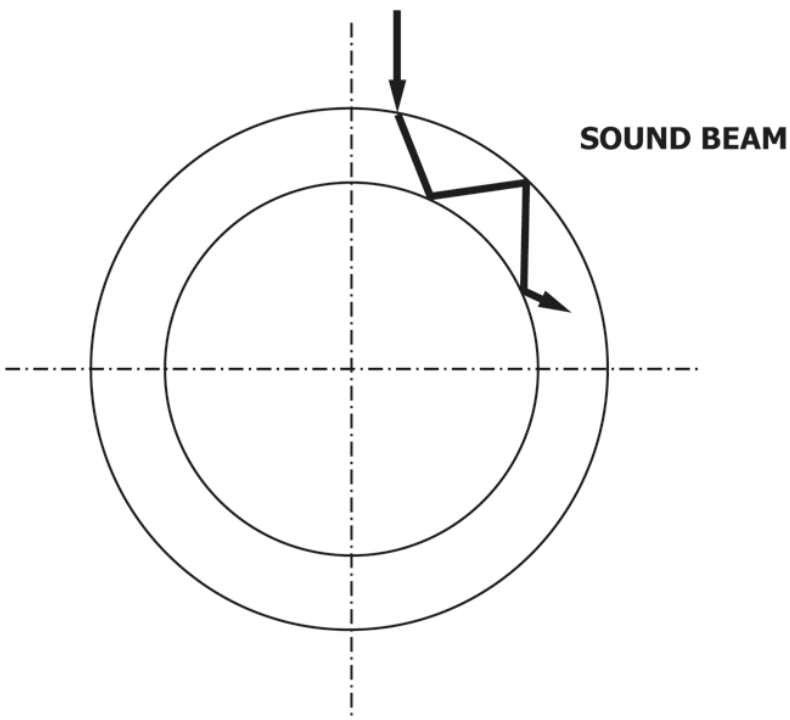


FIG. 1 Circumferential Propagation of Sound in a Pipe or Tube Wall

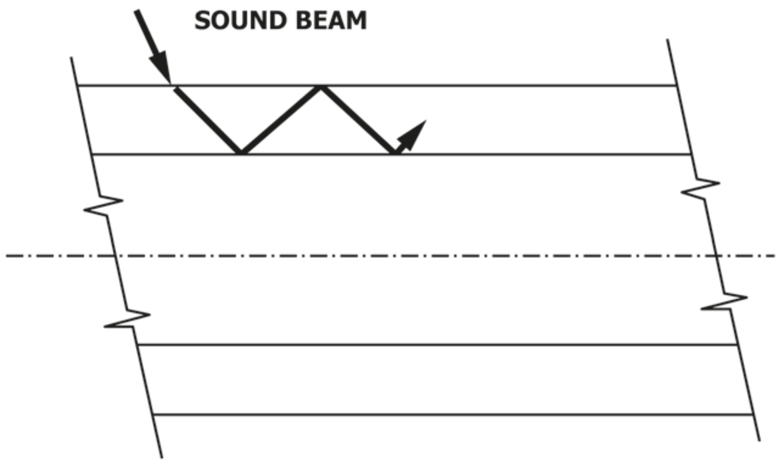


FIG. 2 Axial Propagation of Sound in a Pipe or Tube Wall

6.1.14 Qualification of Nondestructive Agencies. If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.1.15 Level of personnel qualification. (See 7.1)

7. Personnel Qualification

7.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, ISO 9712, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

8. Surface Condition

8.1 All surfaces shall be clean and free of scale, dirt, grease, paint, or other foreign material that could interfere with interpretation of examination results. The methods used for cleaning and preparing the surfaces for ultrasonic examination shall not be detrimental to the base metal or the surface finish. Excessive surface roughness or scratches can produce signals that interfere with the examination.

9. Apparatus

9.1 Instruments shall be of the pulse echo type and shall be capable of detecting the reference notches of the types described in Section 11 to the extent required in the standardization procedure described in Section 12. An independent channel (or channels) of instrumentation shall be employed to individually monitor the responses from the longitudinal and, when required, transverse oriented search units. The instrument pulse repetition rate shall be capable of being adjusted to a sufficiently high value to ensure notch detection at the scanning rate employed. The instrument shall be capable of this pulse repetition rate without false indications due to spurious reflections or interference from other instruments and search units being used for simultaneous examinations in other directions or along other scan paths.

9.1.1 The frequency and bandwidth of the instrument and search unit shall be capable of being selected to produce a satisfactory signal-to-noise ratio for the detection of the required notches as compared to background "noise" response from irregularities such as grain boundaries and surface roughness.

9.2 Search unit frequency shall be selected to produce a desirable "signal-to-noise" ratio (S/N), from the material to be examined, at the specified sensitivity. A S/N value of at least 3 to 1 is usually considered to be minimum. A higher minimum value is desirable and may be specified by the contracting agency.

9.2.1 Select a search unit size, frequency and refracted angle (or corresponding parameters for non-contact techniques) to produce an approximate 45 degrees beam-center shear wave in the tube or pipe wall. For material with an outside diameter-to-thickness ratio less than 7, a lower refracted angle (or corresponding parameters for non-contact techniques) must be used to ensure intersection with the inside surface. This does not ensure detection of midwall discontinuities (See Reference 1).

9.3 The positions of all conveyor and drive mechanisms must be set to support and feed the material to be examined in a stable manner and at the desired scan "pitch" (helix). For small tubes, support mechanisms must be used in the examination station to prevent any transverse motion with respect to the search unit beam during scanning. If larger material that is not straight is to be examined the search units may have to be supported in a "follower" mechanism to compensate for this.

10. Couplant

10.1 For piezoelectric-based search units (non-contact techniques do not require couplant), a couplant such as water, oil, or glycerin, capable of conducting ultrasonic vibrations between the search unit and the pipe or tube being examined shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all the additives should not to be detrimental to the surface condition of the pipe or tube, and shall wet the surface of the material to provide adequate coupling efficiency. To prevent spurious signals or loss of sensitivity, or both, care must be taken to avoid the presence of air bubbles in the couplant.

NOTE 2—In the contact method, some couplants result in better ultrasonic transmission when the tubing is precoated several hours before the examination.

11. Reference Standards

11.1 A reference standard of a convenient length shall be prepared from a length of pipe or tube of the same nominal diameter, wall thickness, material, surface finish, and acoustical properties as the material to be examined. The reference pipe or tube shall be free of discontinuities or other conditions producing indications that can interfere with detection of the reference notches.

11.2 Longitudinal and, when required by the contracting agency, transverse reference notches shall be placed on both the outside and inside surfaces of the reference standard to ensure satisfactory examination sensitivity near each of these boundaries.

11.3 Reference notches shall be separated sufficiently (circumferentially or axially, or both) to preclude interference and interpretation difficulties.

11.4 All upset metal, burrs, etc., adjacent to the reference notches shall be removed.

11.5 The notch dimensions, which are length, depth, and width (and for V-notches, the included angle) must be decided upon by the using party or parties. Fig. 3 illustrates the common notch configurations and the dimensions to be measured (Note 3). Reflection amplitudes from V-, square-, and U-shaped notches of comparable dimensions may vary widely depending on the angle, frequency, and vibrational mode of the interrogating sound beam.

NOTE 3—In Fig. 3 (*a*), (*b*), and (*d*), the sharp corners are for ease of illustration. It is recognized that in normal machining practice, a radius will be generated.

11.5.1 The notch depth shall be an average measured from the circular tubing surface to the maximum and minimum penetration of the notch. Measurements may be made by optical, replicating, or other agreed upon techniques. Unless specified otherwise by the using party or parties, the notch depth shall be within ±0.0005 in. (0.013 mm) of the specified value for notches 0.005 in. (0.13 mm) or less in depth, and within + 10, − 15 % of the specified value for notches over 0.005 in. in depth. At the option of the testing agency, shallower notches may be used to provide a more stringent examination.

NOTE 4—For as-rolled or scaly pipe or tube surfaces, it may be necessary to modify 11.5.1. Two acceptable modifications are listed below. Modification (*a*) is preferred; however, modification (*b*) may be used unless otherwise specified.

(*a*) The circular pipe or tube surface may be smoothed or prepared in the notch area, or

(*b*) The notch depth shall be within ±0.001 in. (0.025 mm), or + 10, − 15 % of the specified depth, whichever is greater.

11.5.2 When notch tolerances are specified by the using party or parties, tolerances may often include only negative values with zero positive deviation allowed so that sensitivity is never reduced below a specified minimum value. The use of smaller notches by the examination agency is permissible, provided that concurrence is obtained from the contracting agency.

NOTE 5—The amplitude of indications obtained from reference notches may not be linearly proportional to notch depth. This depends upon the intercepting beam width to notch length.

11.5.3 The width of the notches shall be as small as practical, but should not exceed twice the depth.

11.6 Other types and orientations of reference reflectors may be specified by the using party or parties.

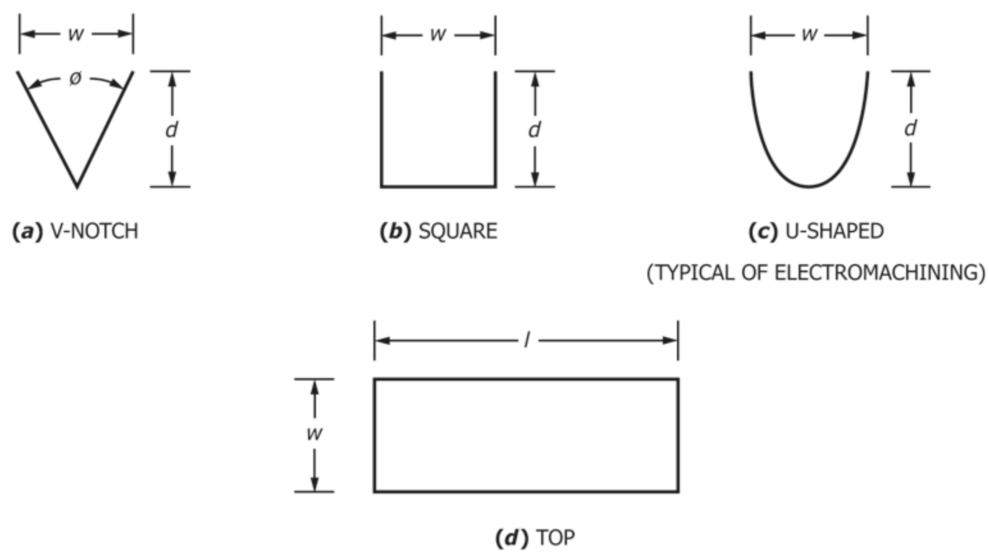


FIG. 3 Common Notch Shapes

12. Standardization of Apparatus

12.1 *Static Standardization*—Using the reference standard specified in Section 11, adjust the equipment to produce clearly identifiable indications from both the inner and outer surface notches. The response from the inner and outer surface notches should be as nearly equal as possible. Use the lesser of the two responses to establish the rejection level. On large diameter or heavy wall pipe and tubing, if the inner and outer surface notch amplitude cannot be made equal because of material soundpath distance and inside diameter curvature, a separate rejection level may be established for the inner and outer surface notches.

NOTE 6—*Distance-Amplitude Correction*— A method of compensating for the reduction in ultrasonic signal amplitude as a function of material sound-path distance may be employed. Details of the procedures used to establish and apply the distance-amplitude correction (DAC) curve shall be established by the using party or parties.

12.2 *Dynamic Standardization*—Standardize the equipment under dynamic conditions that simulate the production examination. The pipe or tubing to be examined and the search unit assembly shall have a rotating translating motion relative to each other such that a helical scan path will be described on the outer surface of the pipe or tube. Maintain the speed of rotation and translation constant within ±10 %. Axial scanning with circumferential indexing may be used to provide equivalent coverage.

12.3 The pitch of the feed helix shall be small enough to ensure at least 100 % coverage at the examination distance and sensitivity established during standardization. Coverage shall be based upon the maximum effective size of the search unit, the pulse density for each instrument channel and the helix.

13. Procedure

13.1 Examine the pipe or tubing with the ultrasound transmitted in both circumferential directions for longitudinal discontinuities and, when specified, in both axial directions for transverse discontinuities, under identical conditions used for equipment standardization (see Note 7).

NOTE 7—Identical conditions include all instrument settings, mechanical motions, search unit position and alignment relative to the pipe or tube, liquid couplant, and any other factors that affect the performance of the examination.

NOTE 8—If a requirement exists for both longitudinal and transverse notches the following three options are available:

(*a*) Each pipe or tube is passed through a single-channel examination station four times, twice in each direction,

(*b*) Each pipe or tube is passed through a two-channel examination station twice, once in each direction, or

(*c*) Each pipe or tube is passed through a four-channel examination station once.

13.2 *Standardization Checks*—Periodically check the dynamic standardization of the equipment by passing the reference standard through the examination system in accordance with 12.2. Make these checks prior to any examination run, prior to equipment shutdown after an examination run, and at least every four hours during continuous equipment operation. Restandardize the equipment in accordance with 12.1 and 12.2 any time the equipment fails to produce the signal amplitudes or other conditions for rejection within the tolerances agreed upon with the contracting agency. In the event that the equipment does not meet this requirement, reexamine all pipe or tubing examined since the last acceptable standardization after restandardization has been accomplished.

13.2.1 When required by the purchaser, more specific restandardization criteria may be specified.

13.3 For many tubular sizes and examination arrangements, there will be a reflection from the entry surface of the pipe or tube. This signal may be observed, but not gated, as a supplement to the required checking of the reference standard to provide increased assurance that the equipment is functioning properly. If such a signal does not exist, make more frequent equipment standardization checks.

13.4 Do not make any equipment adjustments, during examination, unless the complete standardization procedure described in Section 12 is performed after any such adjustment.

13.5 The examination shall be applied to 100 % of the pipe or tubing unless otherwise specified.

NOTE 9—Some traversing mechanisms do not allow examination of pipe or tube ends. When this condition exists, clearly indicate the extent of this effect, per tube, in the examination report.

14. Interpretation of Results

14.1 All indications that are equal to or greater than the rejection level established during standardization as described in Section 12, using the agreed upon reference indicators described in 11.5, shall be considered as representing defects and may be cause for rejection of the pipe or tube. Alternatively, the using party or parties may specify specific acceptance criteria.

14.2 If, upon further examination of the pipe or tube, no rejectable indications are detected, the material shall be considered as having passed the ultrasonic examination, except as noted in 13.2.

NOTE 10—Rejected pipe or tubes may be reworked in a manner acceptable to the purchaser. If, upon ultrasonic reexamination of the reworked pipe or tube, no rejectable indications are detected, the material should be considered as having passed the ultrasonic examination.

NOTE 11—Care should be exercised to ensure that reworking a pipe or tube does not change its acceptability with respect to other requirements of the material specification such as wall thickness, ovality, surface finish, length, and the like.

15. Documentation

15.1 When a report is required, it shall contain such information as is mutually considered adequate to document that the examination of the pipe or tubes supplied meets the requirements of this practice, and any modifications specified in the contractual agreement.

15.2 When a "third party" examination is required, as might be performed by an independent examination facility, and to the extent specified in the contractual agreement, a permanent record containing objective evidence of the examination results shall be obtained for pipe or tube examined. This may be in the form of a strip chart recording or computerized data of the ultrasonic instrument output during the examination. It shall contain recordings of all standardizations and standardization checks and should be annotated to provide a positive correlation between examination record for each reject pipe or tube and the corresponding pipe or tube. The supplier shall maintain a report of the examination on file. When requested by the customer, a report of the examination shall be submitted to the customer. The report shall include at least the following information:

15.2.1 Identification of the material by type, size, lot, heat treatment, and any other pertinent information.

15.2.2 Identification of the examination equipment and accessories.

15.2.3 Details of the examination technique, including examination speed, examination frequency, and end effects if any.

15.2.4 Description of the reference standard, including the actual (measured) dimensions of the artificial reference reflectors.

15.2.5 Description of the distance-amplitude correction procedure, if used.

15.2.6 Examination results.

16. Keywords

16.1 angle beam; nondestructive examination; pipe; tubing; ultrasonic examination

ANNEXES

(Mandatory Information)

A1. EXAMINATION OF PIPE AND TUBING FOR SPECIAL AND SAFETY APPLICATIONS

A1.1 Introduction—When the end use of pipe or tubing depends critically upon freedom from discontinuities over a certain maximum size, certain additional ultrasonic examination procedures are required to assure that the required quality standards are met. The immersion method is almost always required for examining tubes for these uses. In some instances, such as field examination or where part contact with water is undesirable, the contact method, or non-contact technique, for instance as described in Guide E1774, may be employed.

A1.1.1 This practice is intended for use with tubular products of any diameter and wall thickness, provided that proper procedures, as described herein, are followed. These procedures are intended to ensure that proper refraction angles and beam shapes are used to provide full volume coverage of pipes and tubes, including those with low ratios of outside diameter-to-wall thickness, and to avoid spurious signal responses when examining small-diameter, thin-wall tubes.

A1.2 Summary of Practice—Pulsed ultrasonic angle beams by either the surface contact or immersion method shall be used. Fig. A1.1 illustrates characteristic angle beam ultrasound entry into the wall of a pipe or tube in the circumferential direction to detect longitudinal defects and in the axial direction to detect transverse defects, when required. The incident and refracted beams in these cases are pictured as being generated by a cylindrically focused immersion search unit. In pipes and tubes with diameters several times larger than the length of a contact search unit, the general beam shapes are approximately the same.

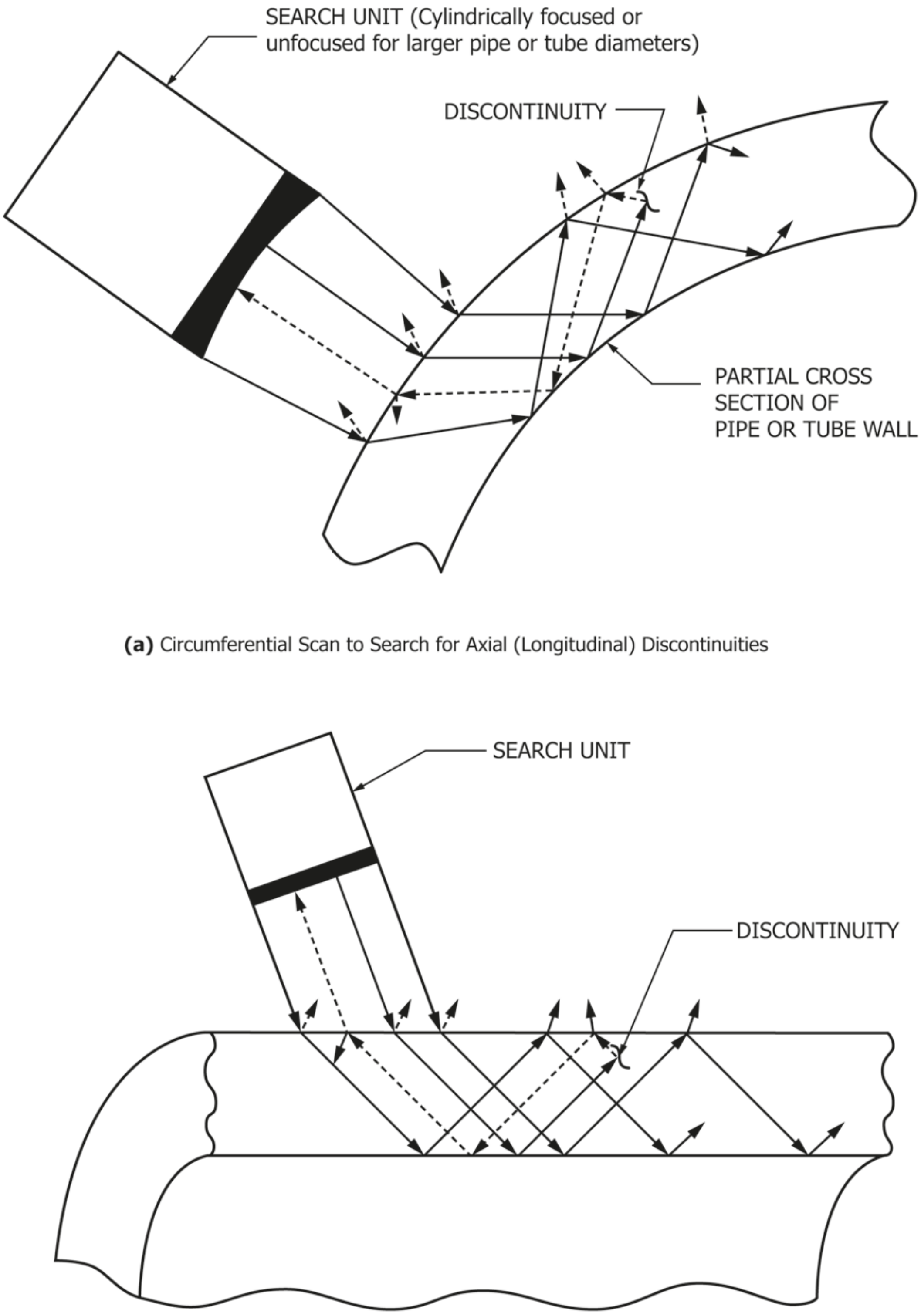
A1.3 Additional Apparatus Requirements

A1.3.1 Although contact search units may be used for small quantity and field examinations of pipes and tubes, cylindrically (line) focused immersion search units are preferred for critical examinations and for larger quantities (See References (**2**), (**3**) and (**4**)). Search unit element size and focused beam length shall be suitable for achieving reliable detection of defects equivalent in size to the reference notches at the scanning pitch or index used. When examination of heavy-wall pipes and tubes is required the focal length, refraction angle and included beam angle of focused search units shall be suitable for complete through-wall coverage (See (**1**)).

A1.3.2 The beam length of the search unit in the wall material must be either longer or shorter than the length of longitudinal notches in the reference standard, by an amount that is no less than the "pitch" (linear advance per revolution) of the helical scan path (see A2.1). This is necessary to ensure detection of discontinuities that are as long as the notches in spite of their random locations with respect to the scan path, (See Annex A2).

A1.3.3 The focal length of a focused immersion search unit should equal the pipe or tube radius plus a convenient water path length so that it may be focused on the pipe or tube centerline (See (**4**)).

A1.3.4 The angle of the central beam of the search unit, with respect to a perpendicular to the tangent to the surface at the point of beam incidence, shall be adjusted to produce a suitable refraction angle in the pipe or tube wall to provide complete coverage of the pipe or tube wall thickness (See (**1**)). A refraction angle of 45 degrees is typically used when examining pipe or tubes with a diameter-to-wall thickness ratio of no less than about 10 to 1. For many materials a 45 degree refraction angle may be achieved with a beam incidence angle of about 18 to 19 degrees. This may be achieved in the immersion method by parallel offsetting the beam centerline from a perpendicular to a tangent of the surface by a distance equal to ⅙ of the outside diameter of the pipe or tube. This is often a convenient initial adjustment during system standardization.



(a) Circumferential Scan to Search for Axial (Longitudinal) Discontinuities

(b) Axial Scan to Search for Circumferential (Transverse) Discontinuities

FIG. A1.1 Beam Propagation in Pipe or Tube Walls

A1.4 Additional Reference Standard Requirements

A1.4.1 Outer surface and inner surface longitudinal reference notches may be placed near one end of the reference standard separated by a sufficient distance from each other and from the end to preclude interference and interpretation difficulties, but close enough to each other to minimize the time required in scanning from one to other to achieve good signal balance during set-up. For ease of fabrication, the inner surface notch should be nearer the end of the pipe or tube. When required, transverse outer surface and inner surface reference notches are typically placed in the same manner near the opposite end of the reference standard from the longitudinal notches. Although not mandatory, this practice enables all notches to be placed far enough from the ends to insure good support of the material end nearest the search unit(s) during set-up, and the inner surface notches to be near ends to facilitate insertion of the fabrication and verification means. This procedure becomes less critical for material of larger diameters and stiffness.

A1.5 Static Standardization—Using the reference standard specified in Section 11, adjust the equipment to produce clearly identifiable indications from both the inner and outer surface notches. The relative responses from both the inner and outer surface notches should be as nearly equal as possible and practical. Some differences in this procedure are required, as described below, depending upon whether the contact or immersion technique is employed.

A1.5.1 Set the positions of all conveyor and drive mechanisms to support and feed the material to be examined in a stable manner and at the desired scan "pitch", considering conditions for achieving satisfactory "worst case interception" and required scan path overlap. (See Annex A2.)

A1.5.2 *Contact Examination Technique*—For field examination, or in other cases where immersion examination is not practical, the contact technique may be employed. It is important to note however that it is more difficult to obtain repeatable and accurate results with this technique because (See (**2**)):

(a) It is difficult to maintain uniform sensitivity during scanning due to lack of constant pressure on the search unit and inconsistent couplant coverage;

(b) Unless special "involute" (**5**), or similar, search units are used it is impossible to obtain the primary benefit of focusing which is the uniformity of sensitivity versus thickness which results from the production of constant refraction angles throughout the width of the beam;

(c) With a given search unit wedge it is impossible to vary the incident angle to achieve good balance of the signals from outer surface and inner surface notch targets or to lower the incidence angle to obtain good through-wall coverage on thick-wall pipe or tubes;

(d) Maintenance problems may result from wear of the search unit face plates; and,

(e) When manual scanning is employed it is difficult to insure that total surface coverage or any prescribed amount of scan overlap has been achieved.

A1.5.3 When contact examination is performed, the following selection and standardization procedure shall be used unless an alternate procedure is approved by the contracting agency.

(a) Select a search unit size, frequency and wedge angle and shape to produce an approximately 45 degree beam-center shear wave in the tube or pipe wall. If it is determined that a lower refraction angle would be beneficial, a wedge to produce that angle may be used.

(b) Apply the search unit, with a suitable film of couplant, to the surface of the reference standard in the vicinity of the longitudinal reference notches. Direct the search unit beam in one circumferential direction.

(c) While carefully maintaining uninterrupted coupling and constant pressure on the search unit, move it toward and away from the outer surface longitudinal notch to achieve the maximum signal response from it by a beam reflection from the inner surface which is beyond the interface signal on the display screen of the instrument. Adjust the gain control to set the peak response at this reflection location (node) to 80 % of full screen height (FSH).

(d) Without changing the gain control setting from that determined in Step (*c*) above, move the search unit to the vicinity of the inner surface longitudinal notch and repeat the scanning procedure until the signal from that notch, at a node adjacent to that used for the outer surface notch signal, is maximum. Record the peak amplitude of the signal from the inner surface notch. If this signal is higher than 80 % FSH, lower the gain to bring it to 80 % FSH and move again to the outer surface notch and record its peak amplitude at the new gain setting. The relative response from the inner and outer surface notches shall be as nearly equal as possible by selection of the pair of adjacent inner surface and outer surface notch signal nodes are observed. Use the lesser of the two responses to establish the rejection level. On large-diameter or heavy-wall pipe and tubing, if the inner and outer surface notch signal amplitudes cannot be equalized because of material sound path distance and inside diameter curvature, a separate rejection level may be established for the inner and outer surface notches, or, in this case, DAC may be used to balance the signal amplitudes from the outer surface and inner surface notches.

(e) Repeat steps (*a*) through (*d*) while scanning from the opposite circumferential direction.

(f) Repeat the above steps while scanning in both axial directions if detection of transverse notches and discontinuities is required by the user or contracting agency.

A1.5.4 *Immersion Examination Technique*—This is the preferred technique whenever practical (**2**). Any of the apparatus types listed in Note 1 (4.1) may be used for this purpose. The following selection and standardization procedure shall be used unless an alternative is approved by the contracting agency.

A1.5.5 Using the guidelines listed below, select a cylindrically focused (line focused) search unit (**3**) of appropriate frequency, beam length and focal length for the material to be examined and to the sensitivity level (notch sizes) specified by the user or contracting agency. In cases where the type of examination, material dimensions or other properties make the use of spherically or flat focused search units more appropriate either of these types may be used in place of cylindrically focused units.

(a) The frequency shall be selected to produce a desirable signal-to-"noise" ratio (S/N) from the material to be examined

at the specified sensitivity. A S/N value of at least 3 to 1 is usually considered to be a minimum. A higher minimum value is desirable and may be specified by the contracting agency.

(b) The focal length must be equal to the pipe or tube radius plus a convenient waterpath length so that the search unit may be focused on the central axis of the pipe or tube after normalization (**4**). For very large-diameter material where this requirement is found to be impractical search units of other focal lengths or unfocused units may be used.

(c) The beam width, as measured between -3 dB points on a pulse-echo profile as described in Guide E1065, must be either longer or shorter than the length of the longitudinal notches in the reference standard by the amount of the scan pitch to be employed. This is necessary to ensure consistent "worst case" interception of discontinuities that are as long as the notches in spite of their random location with respect to the scan path. (See Annex A2.)

(d) Position the search unit so that the length of its focused beam is aligned with the long axis of the pipe or tube.

(e) With the water path length adjusted to focus the beam approximately on the outer surface of the pipe or tube, normalize the search unit by adjusting its angulation and offset to peak its response from the surface.

(f) Change the water path so that it is equal to the focal length of the search unit minus the radius of the tube. Readjust the angulation and offset if necessary to renormalize by repeaking the interface signal.

(g) Offset the search unit in a direction that is parallel to its centerline and perpendicular to the longitudinal axis of the tube by the amount required to establish a beam-center incidence angle that will produce the desired refraction angle in one circumferential direction in the tube wall. (For many materials a satisfactory initial offset distance is ⅙ of the tube diameter.) For thick-wall tubes a lower refraction angle may be required for examination of the entire thickness (**1**). Alternatively, the search unit may be angulated in a plane perpendicular to the tube axis to produce the incidence angle.

(h) Move the reference standard to center the outer-surface notch in the search unit beam. Rotate the tube without translation (that is, without motion along its longitudinal axis) and observe on the instrument display screen the motion of the notch signal away from any residual interface signal. The amplitude should decrease and increase as successive reflections of the beam from the inner and outer surfaces intersect the outer surface notch as it moves to various node positions away from the search unit. Select a convenient node well away from the "direct-in" intersection of the beam on the outer surface notch (which coincides with the position of the interface signal). Adjust the gain to set the amplitude of the signal at 80 % FSH and note its horizontal position on the display.

Note— Alternatively, set-up on the inner surface notch may be performed before set-up on the outer surface notch, as described in step (*h*) above. This inner surface notch signal must be well beyond the direct-in signal from the outer surface notch. The outer surface notch signal subsequently used for standardization should then be from the node immediately beyond the inner surface notch signal to obtain the best condition for attempting to equalize both gated signals in the following step (*i*).

(i) Move the reference standard to center the inner surface notch in the beam. Rotate the pipe or tube as for the outer surface notch and note the amplitude of the inner surface notch signal that appears just before the selected outer surface notch signal.

(j) Make small adjustments to the offset (or angulation) and to the water path length while alternately observing and attempting to equalize the outer surface and preceding inner surface notch signal amplitudes. Set the higher of the two signals to 80 % FSH and use the lesser of the two signals to establish the rejection level. Set the position and duration of the instrument alarm gate to include both of these signals. For examinations that require stopping and evaluating or marking all relevant indications, or both, set the alarm activation threshold at 40 % FSH. Record all search unit position settings, instrument control settings and standardization signal levels on an examination record sheet.

(k) Repeat the above steps while scanning in the opposite circumferential direction.

(l) When axial scanning for transverse indications is required, repeat the above steps with the search unit angled in first one, then the other axial direction and using translation rather than rotation of the reference standard to select response nodes from outer surface and inner surface notches.

A1.6 Dynamic Standardization—Standardize the equipment under dynamic conditions that simulate the production examination. The pipe or tubing to be examined and the search unit assembly shall have a rotating translating motion relative to each other such that a helical scan path will be described on the outer surface of the pipe or tube. Maintain the speed of rotation and translation constant within ±10 %. Axial scanning with circumferential indexing may be used, especially on larger material, to provide equivalent coverage. A method for achieving the required conditions is described below.

A1.6.1 The pitch of feed helix shall be small enough to ensure 100 % coverage at the examination distance and sensitivity established during static standardization per A1.5. Annex A2 describes how maximum allowable pitch for stable detection may be determined from the length of the longitudinal reference notches and the minimum beam length of the search units.

A1.6.2 A preferred method for dynamic scanning, applicable to all diameters but especially for smaller diameter material, for example, less than 4 inches (100 mm) in diameter, is for the examination system to produce a rotating and translating relative motion between the pipe or tubing being examined and the search unit(s). Run the reference standard with random initial translational and angular orientation through the examination station at full speed and scan pitch and observe, during multiple runs of the standard, the stability of the gated alarm signals from all notches in the reference standard on a strip-chart recorder or other means for observing signal amplitude stability or alarm function. In the absence of an alternate procedure approved by the contracting agency, the peak signal amplitudes must remain constant within 10 % FSH for the number of successive runs specified in an approved examination procedure (a minimum of six is suggested) or, if another defect alarm device is used, it shall provide consistent operation for the specified number of runs. If indexed axial scanning is used, the same stability verification procedure and criteria shall apply.

A1.7 Additional Mandatory Procedure Requirements

A1.7.1 *Standardization Checks*—Periodically check the standardization of the equipment by passing the reference standard through the examination system. Make these checks prior to any examination run, prior to equipment shutdown after an examination run, and at least every hour during continuous equipment operation. Restandardize and reexamine the material if necessary, in accordance with the following procedures, unless otherwise specified by the contracting agency.

A1.7.2 *Restandardization*—If any notch in the reference standard fails to actuate an alarm, or, where defect analysis is made from a strip chart recording of signal amplitudes, if the deviation from the recorded amplitude of the initial standardization signal exceeds 10 % of that amplitude, portions of the static and dynamic standardization procedures of A1.6 shall be repeated until satisfactory operation is obtained. Then the following steps shall be taken, depending upon the nature of the failure.

A1.7.3 *Failure of Alarm Actuation*—When alarm actuation is the only defect indication used, if a notch in the reference standard fails to actuate the flaw alarm during a standardization check, all lengths of material run since the last satisfactory standardization check shall be reexamined after the system has been successfully restandardized.

A1.7.4 *Decrease of Recorded Notch Signal Amplitude of Between 10 and 20 % and No Recorded Indications*—In the case of a recorded examination wherein the signal amplitude from any notch in the rerun reference standard has decreased from the average value of the initially recorded amplitudes by more than 10 % but less than 20 %, no rerun of parts is required after restandardizing if, since the last satisfactory standardization check, there were no recorded unrejected signal indications that were greater than 50 % of the average amplitude of the initially recorded signals. However, restandardization shall be performed to bring the signal amplitude to within 10 % of the average of the initially recorded values before examination is resumed.

A1.7.5 *Decrease of Recorded Notch Signal Amplitude of Over 20 % or of Between 10 and 20 % With Indications*—If the rerun recorded value is less than the average of the initial recorded amplitudes by more than 20 %, or if the decrease is between 10 % and 20 % and there are unrejected indications of greater than 50 % of the average initial standardization amplitude, the entire lot of material examined since the last satisfactory standardization check shall be reexamined after restandardization.

A1.7.6 *Increase of Recorded Notch Signal Amplitude*—If any recorded notch signal amplitude is found to have increased by more than 10 % above the average of the initially recorded values, restandardization shall be performed to bring the signal level to within that range. If the increase is between 10 % and 20 % no rerun of material is required. If the increase is greater than 20 %, and there have been indications rejected since the last satisfactory standardization check, the entire lot of material run since the last standardization check shall be reexamined.

A2. RESTRICTION ON THE SELECTION OF SCAN PITCH

A2.1 Determination of Scan Pitch—The helical scan pitch, however generated, must not exceed the absolute difference between the length of the longitudinal reference notches and the effective length of the search unit beam. This requirement may be stated as:

$$P \leq |N - B|$$

where:

N = Notch Length
B = Beam Length

A2.1.1 This restriction arises from consideration of the "worst case interception" of the longitudinal notch (and therefore defects of that length) by the search unit beam, regardless of the random initial location of the notch with respect to the scan pattern. The actual length of the worst case interception may be represented by:

$$I_{wc} = \{N + B - P\}/2$$

A2.1.2 The length of the "best case" random interception of the notch by the beam is equal either to "N" or "B", depending on which is longer. The fractional percentage change in notch interception length, and therefore signal amplitude, between worst and best interceptions may be obtained by dividing I_{wc} by either "N" (if "B" is longer) or by "B" (if "N" is longer); that is:

$$I_{wc}/N = 1/2 + \{B - P\}/2N$$

or

$$I_{wc}/B = 1/2 + (N - P)/2B$$

A2.1.3 It is seen from these equations that if the pitch is equal to either the beam length (if it is greater than N) or to the notch length (if it is greater than B), the percentage change between best and worst case random interceptions of the notch by the beam will be 0.5 or 6 dB. No acceptable standardization repeatability can be provided in that case. However, if P = N - B is substituted in the first of the above equations, or P = B - N is substituted in the second, the ratio of worst to best case interception is 1.0. This indicates no signal variation due to random alignment and is the prescribed condition for maximum pitch if "invariant" notch detection is to be assured.

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(2) Bar-Cohen, Y., "Introduction to Ultrasonic Testing," *Nondestructive Testing Handbook* , 2nd Ed., Vol. 7, pp 220,221, 1991, Am. Soc. for Nondestructive Testing, Columbus, Ohio.

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(4) Beck, K.H., "Ultrasonic Transducer Focusing for Inspection of Cylindrical Material," *Materials Evaluation*, Vol.49, No. 7, July 1991, pp 876 - 882, ASNT.

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STANDARD PRACTICE FOR ULTRASONIC TESTING OF THE WELD ZONE OF WELDED PIPE AND TUBING

SE-273

(Identical with ASTM Specification E273-15.)

Standard Practice for Ultrasonic Testing of the Weld Zone of Welded Pipe and Tubing

1. Scope

1.1 This practice describes general ultrasonic testing procedures for the detection of discontinuities in the weld and adjacent heat affected zones of welded pipe and tubing by scanning with relative motion between the search unit and pipe or tube. When contact or unfocused immersion search units are employed, this practice is intended for tubular products having specified outside diameters ≥2 in. (≥50 mm) and specified wall thicknesses of 1⁄8 to 11⁄16 in. (3 to 27 mm). When properly focused immersion search units are employed, this practice may also be applied to material of smaller diameter and thinner wall.

NOTE 1—When contact or unfocused immersion search units are used, precautions should be exercised when examining pipes or tubes near the lower specified limits. Certain combinations of search unit size, frequency, thin–wall thicknesses, and small diameters could cause generation of unwanted sound waves that may produce erroneous examination results.

1.2 All surfaces of material to be examined in accordance with this practice shall be clean from scale, dirt, burrs, slag, spatter or other conditions that would interfere with the examination results. The configuration of the weld must be such that interfering signals are not generated by reflections from it. Treatment of the inner surface and outer surface weld beads such as trimming ("scarfing") or rolling is often required to remove protuberances that could result in spurious reflections.

1.3 This practice does not establish acceptance criteria, they must be specified by the using parties.

1.4 The values stated in inch-pound units are to be regarded as the standard. The SI equivalents are in parentheses and may be approximate.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

Recommended Practice SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondesctructive Testing Personnel

2.3 *ISO Standard:*

ISO 9712 Non-destructive Testing—Qualification and Certification of NDT Personnel

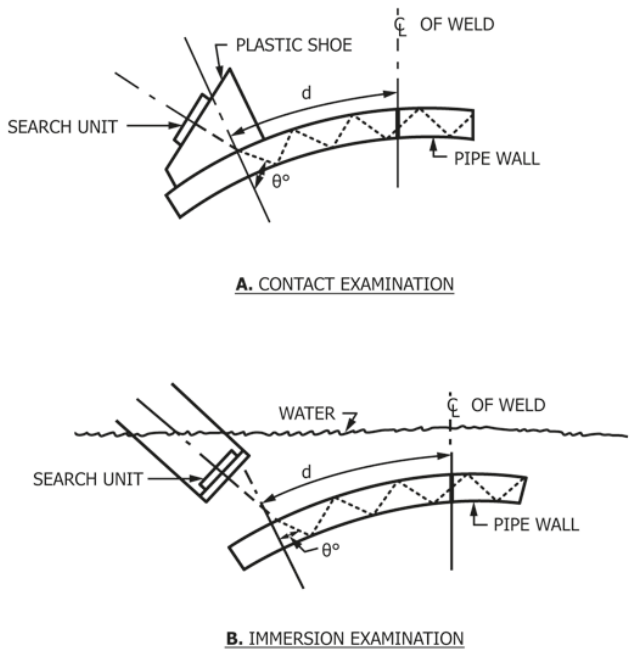
3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E1316.

4. Summary of Practice

4.1 A pulsed ultrasonic angle beam shall be propagated in the wall of the pipe or tube by either the surface contact or immersion method. Fig. 1 illustrates the characteristic oblique sound entry into the pipe wall for both contact and immersion examination from one search unit.

NOTE 2—The immersion examination method may include tanks, wheel search units, or bubbler systems.



NOTE 1—θ = 35° through 70°.

FIG. 1 Angle Projection of Ultrasonic Wave

4.2 The weld line shall be examined from both sides to ensure detection of imperfections with a shape or orientation that produces a preferential direction of reflection.

5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for detecting weld discontinuities such as lack of fusion, pin holes, lack of penetration, longitudinal cracks, porosity and inclusions by the ultrasonic pulse-reflection method.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, ISO 9712, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in E543. The applicable edition of E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement, including:

6.4.1 Type, dimension, and number of reference reflectors to be placed in the reference standard,

6.4.2 Standardization of examination sensitivity intervals,

6.4.3 Examination frequency,

6.4.4 Pulse repetition rate,

6.4.5 Sound beam orientation and number of beams used, and

6.4.6 Procedure and use of distance amplitude compensation.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with paragraph 1.2 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Since acceptance criteria are not specified in this standard, they shall be specified in the contractual agreement.

6.7 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7. Procedure

7.1 *Apparatus*

7.1.1 The instruments and accessory equipment shall be capable of producing, receiving, amplifying, and displaying electrical pulses at frequencies and pulse rates deemed necessary by the using parties. They shall be capable of distinguishing the reference reflectors described in Section 7.2 to the extent required in the standardization procedure outlined in Section 7.3

7.1.2 For pulse echo examination systems, the contact or immersion search units should produce ultrasonic waves that travel in the pipe or tube wall at a refracted angle of from 35° to 70° and perpendicular to the weld seam. For pitch/catch or through transmission examination systems, orientation of the entry sound beam other than perpendicular to the weld seam may be required.

7.1.3 *Couplant*—A liquid such as water, oil, glycerin, etc., capable of conducting ultrasonic vibrations from the search unit to the pipe or tube shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all additives should not be detrimental to the surface condition of the pipe or tubing and should wet the surface. In examining electric-resistance-welded pipe, water-soluble oil used in cooling the pipe serves as a satisfactory couplant.

7.1.4 *Distance Amplitude Compensation*—The use of electronic methods to compensate for attenuation losses as a function of ultrasonic metal travel distance may be employed.

7.1.5 *Search Units*—The search unit must be appropriately sized with respect to width and beam included angle to achieve full wall thickness coverage(**1**). Where this can not be achieved with a single search unit propagating in a given direction, two or more search units may be used to scan in each direction. The effective beam length of the search units shall be such that reliable detection of all reference reflectors is accomplished without exceeding the "noise" limits of 7.3.2. The focal length of focused search units shall be at least equal to the radius of the material plus a suitable water path so that initial focus may be on the tube or pipe central axis (**2**).

7.2 *Reference Standards*

7.2.1 A reference standard, of sufficient length to allow verification of system standardization, shall be prepared from a length of pipe or tubing of the same nominal diameter and wall thickness, material, surface finish, and acoustical properties as the material to be examined. The pipe or tube selected for this purpose shall be free of discontinuities or other abnormal conditions that can cause interference with the detection of the reference reflectors. The reference reflectors shall be selected to ensure uniform coverage of the weld at the sensitivity levels prescribed. The reference reflectors most commonly used will consist of machined notches and drilled holes as described in paragraph 7.2.2. All upset metal, burrs, etc., adjacent to the reference reflectors, shall be removed.

7.2.1.1 *Electric Resistance-Welded, Laser-Welded or Butt-Welded Pipe*—Reference reflectors shall be placed in the center of weld seam and in a line parallel to it unless permission is obtained from the contracting or using agency to place the reference reflectors elsewhere in the reference standard. When longitudinal notches are used as reference reflectors, they shall be placed on the outer and inner surfaces of the reference standard and be separated by a sufficient distance to ensure that the response from one reflector does not interfere with that from the other.

NOTE 3—If reference reflectors are placed in a location other than the centerline of the weld seam there is no assurance that the beam is penetrating the weld unless adequate signal response is obtained from the search units scanning the reflector from both sides of the weld. The lower amplitude of response from the two directions must be used in determining the rejection threshold level. Positioning of automatic alarm gates must be such as to respond to the signal from the reference reflector, but also the signals originating from the reflections from discontinuities anywhere in the weld seam itself.

7.2.1.2 *Fusion-Welded Pipe*—The reference reflectors shall be placed in the weld. When longitudinal notches are used as reference reflectors, they shall be placed in the crown of the fusion-weld bead as shown in Fig. 2(*a*). In fusion-welded pipe containing both inside and outside surface weld beads, a longitudinal notch reference reflector shall be placed in the weld-bead crown on both the outside and inside surfaces.

When drilled holes are employed, they shall be drilled radially from both the outside and inside surfaces through 50 % of the wall thickness at the weld-bead crown or such other depth as agreed upon by the user or contracting agency and separated by some distance that guarantees a distinct and separate response from each one (see Fig. 2(*c*) and Fig. 2(*d*)). By agreement between the purchaser and manufacturer, a hole drilled radially 100 % through the pipe wall may be used instead of the 50 % drilled hole (see Fig. 2(*e*)).

NOTE 4—Fill 50 % deep or through-holes with a waterproof filler such as bee's wax to prevent couplant entry. Otherwise, such entry could produce erratic and/or spurious reflections.

Additional reflectors may be used to produce signals at reflection times that define weld-zone extremities for the purpose of establishing alarm gate timing or other means of controlling the examination area. Holes may be drilled radially 100 % through the pipe wall at the weld-zone edges.

7.2.2 The notch dimensions of length, depth, width, and for Fig. 3(*a*) and Fig. 3(*b*) the included angle α shall be decided upon by the using party or parties. Fig. 3 illustrates the commonly accepted notch configurations and the dimensions to be measured.

7.2.2.1 The notch depth (*h*) shall be measured from the adjacent surface to its maximum and minimum penetration. Measurements may be made by optical, replicating or mechanical, or other techniques. Notch depth is commonly specified as a percent of nominal wall thickness with typical values being 10, 12½, or 20 %. A +0/-10 % tolerance is allowable on notch depths.

7.2.2.2 The notch length (*l*) is considered to be the dimension over which the specified depth is maintained.

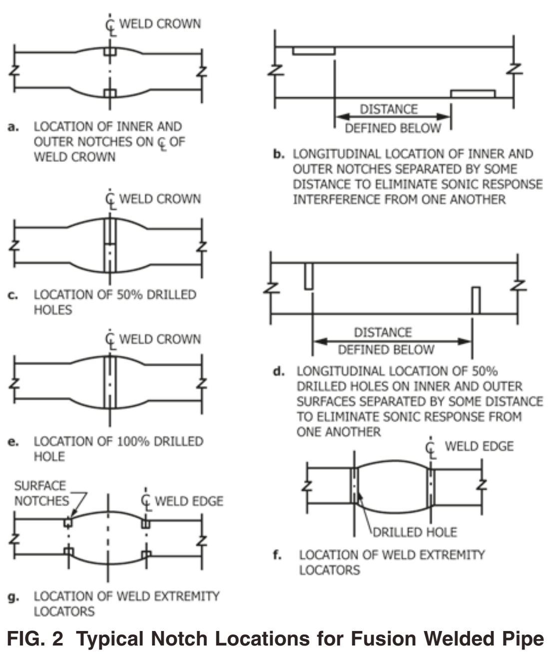


FIG. 2 Typical Notch Locations for Fusion Welded Pipe

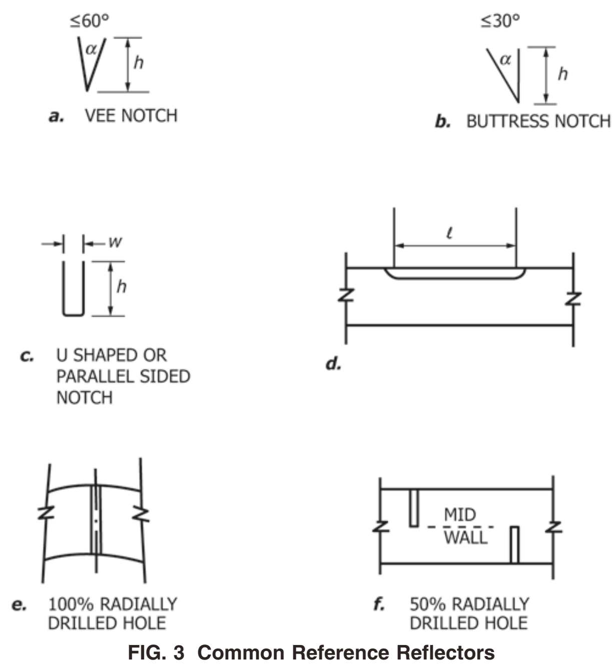


FIG. 3 Common Reference Reflectors

7.2.2.3 The width (*w*) of the notch has negligible effect on standardization and is not a critical dimension.

7.3 *Standardization of Examination Sensitivity*

7.3.1 Using the reference standard specified in 7.2, the equipment shall be adjusted to produce readily distinguished and clearly identifiable indications from both the inner and outer reference reflectors. The relative response to the inner and outer reflectors shall be as near equal as possible. The lesser of the two responses shall be used as the acceptance level.

NOTE 5—Adjustment of water path, adjustment of distance (*d*) in Fig. 1 and angulation of the beam are used to achieve equality. It should be noted however, that detection, or balancing of signals from both outer surface and inner surface notches does not guarantee that examination for radical defects is being achieved throughout the full wall thickness. To effect such examination, especially in pipes and tubes with thicker walls, it is necessary that the beam refraction angle and search unit size (beam included angle for focused units) be selected to be compatible with the ration of diameter-to-wall-thickness of the material as stated in 7.1.5 and described in Reference **(1)**.

7.3.2 Instrument sensitivity and scanning system parameters, such as search unit positioning and scanning, speed, shall be adjusted to produce signal levels that are repeatable from all reference indicators within the limits described below. If a strip chart or similar recorder is used, the amplitude stability of all target indications shall be within 10 % of full scale height (FSH) for several successive scans of the reference standard under conditions simulating those that will be used for the actual material examination. Peak "noise" signal amplitudes observed during scanning over a length of the reference standard equal to at least twice the distance between outer surface and inner surface notches, shall not exceed 40 % of the minimum amplitude of the signals from the reference indicators. If only an audible or other alarm device is used to indicate the presence of rejectable indications, such devices shall be actuated reliably by all reference indicators for several successive scans of the reference standard under conditions simulating those that will be used for the actual material examination.

7.3.3 When weld edge reflectors are used, the equipment shall be adjusted to produce clearly identifiable responses from them that are distinguishable from the reference reflectors used to set rejection limits when the reference standard is scanned in a manner simulating the production examination of the pipe or tubing.

7.3.4 During the standardization procedure, the extent of variation in the dimension (d) (that is, the amount of weld line skew with respect to the search units) that can be tolerated without exceeding the stability limits of 7.3.2 shall be determined and provisions made in the scanning system to ensure that the positions of the search units relative to the weld line are maintained within that limit.

7.4 *Examination Procedure*

7.4.1 Move the pipe or tubing past the search unit with the weld in a fixed position with respect to the search unit. Movement of the search unit with respect to a stationary pipe is satisfactory. During examination, maintain distance (*d*) and angle θ in Fig. 1 and the water path for immersion examination as determined during adjustment of the examination sensitivity. Depending upon the degree of crookedness of the material to be examined, maintenance of these parameters may require the use of "followers" or other devices to enable a stable scan pattern to be maintained.

7.4.2 Certain examination systems using multiple search units or multiple beam transducers compensate for distance (*d*) changes and do not require strict adherence to the maintenance of this dimension during examination. With whatever arrangement is used, the allowable amount of weld line skew shall be determined as in 7.3.4 and scanning provisions made to prevent that limit from being exceeded.

7.4.3 Periodically check the examination sensitivity of the equipment by running the reference standard through the examination system. Make these checks prior to any pipe or tubing examination, prior to equipment shutdown after examination and at least every four hours during continuous equipment operation. Anytime the equipment does not present a clearly defined signal within 10 % of that obtained when the examination sensitivity was established, restandardize the equipment in accordance with Section 7.2.

7.4.4 In the event that the equipment presents a signal more than 10 % below the standardization level, reexamine, when standardization has been accomplished, all pipe and tubing examined subsequent to the last preceding acceptable standardization.

8. Interpretation of Results

8.1 All indications that are equal to or greater than the reference signals established during standardization as described in Section 7.3, or as specified in Section 6, shall be considered as representing defects that may be cause for rejection of the pipe or tube.

8.2 If upon examination of the pipe or tube, no rejectable indications are detected, the material shall be considered as having passed the ultrasonic examination, except as noted in 7.4.4.

9. Keywords

9.1 angle beam; longitudinal welded pipe; longitudinal welded tubing; nondestructive examination; ultrasonic examination

REFERENCES

(1) Beck, K.H., “Ultrasonic Refraction Angles for Inspection throughout the Total Wall Thickness of Tubes and Pipes”, *Materials Evaluation,* Vol. 51, No. 5, May 1993, pp. 607–612.

(2) Beck, K.H., “Ultrasonic Transducer Focusing for Inspection of Cylindrical Material”, *Materials Evaluation,* Vol. 59, No. 7, July 1991, pp. 875–882.

STANDARD PRACTICE FOR EVALUATING PERFORMANCE CHARACTERISTICS OF ULTRASONIC PULSE-ECHO TESTING INSTRUMENTS AND SYSTEMS WITHOUT THE USE OF ELECTRONIC MEASUREMENT INSTRUMENTS

(19) SE-317

(Identical with ASTM Specification E-317-16.)

Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

1. Scope

1.1 This practice describes procedures for evaluating the following performance characteristics of ultrasonic pulse-echo examination instruments and systems: Horizontal Limit and Linearity; Vertical Limit and Linearity; Resolution - Entry Surface and Far Surface; Sensitivity and Noise; Accuracy of Calibrated Gain Controls. Evaluation of these characteristics is intended to be used for comparing instruments and systems or, by periodic repetition, for detecting long-term changes in the characteristics of a given instrument or system that may be indicative of impending failure, and which, if beyond certain limits, will require corrective maintenance. Instrument characteristics measured in accordance with this practice are expressed in terms that relate to their potential usefulness for ultrasonic testing. Instrument characteristics expressed in purely electronic terms may be measured as described in E1324.

1.2 Ultrasonic examination systems using pulsed-wave trains and A-scan presentation (rf or video) may be evaluated.

1.3 The procedures are applicable to shop or field conditions; additional electronic measurement instrumentation is not required.

1.4 This practice establishes no performance limits for examination systems; if such acceptance criteria are required, these must be specified by the using parties. Where acceptance criteria are implied herein they are for example only and are subject to more or less restrictive limits imposed by customer's and end user's controlling documents.

1.5 The specific parameters to be evaluated, conditions and frequency of test, and report data required, must also be determined by the user.

1.6 This practice may be used for the evaluation of a complete examination system, including search unit, instrument, interconnections, fixtures and connected alarm and auxiliary devices, primarily in cases where such a system is used repetitively without change or substitution. This practice is not intended to be used as a substitute for calibration or standardization of an instrument or system to inspect any given material. There are limitations to the use of standard reference blocks for that purpose.[1]

1.7 Required test apparatus includes selected test blocks and a precision external attenuator (where specified) in addition to the instrument or system to be evaluated.

1.8 Precautions relating to the applicability of the procedures and interpretation of the results are included.

1.9 Alternate procedures, such as examples described in this document, or others, may only be used with customer approval.

1.10 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E114 Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing

E127 Practice for Fabrication and Control of Aluminum

[1] Beck, K. H., "Limitations to the Use of Reference Blocks for Periodic and Preinspection Calibration of Ultrasonic Inspection Instruments and Systems," *Materials Evaluation*, Vol 57, No. 3, March 1999.

Alloy Ultrasonic Standard Reference Blocks
E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing
E1316 Terminology for Nondestructive Examinations
E1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments

2.2 *Other Standard:*
IEEE Std 100 *IEEE Standard Dictionary of Electrical and Electronic Terms*

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice see Terminology E1316. Other relevant definitions may be found in IEEE Standard 100.

4. Summary of Practice

4.1 An examination system to be evaluated comprises an ultrasonic pulse-echo instrument, search unit, interconnecting cables, and couplant; for immersion examination systems suitable fixturing is required.

4.2 When checking an entire system to be used for a given examination, test conditions are selected that are consistent with the intended end-use as determined by the user.

4.3 The ultrasonic response from appropriate test blocks is obtained, and presented in numerical or graphical form.

5. Significance and Use

5.1 This practice describes procedures applicable to both shop and field conditions. More comprehensive or precise measurements of the characteristics of complete systems and their components will generally require laboratory techniques and electronic equipment such as oscilloscopes and signal generators. Substitution of these methods is not precluded where appropriate; however, their usage is not within the scope of this practice.

5.2 This document does not establish system acceptance limits, nor is it intended as a comprehensive equipment specification.

5.3 While several important characteristics are included, others of possible significance in some applications are not covered.

5.4 Since the parameters to be evaluated and the applicable test conditions must be specified, this practice shall be prescribed only by those familiar with ultrasonic NDT technology and the required tests shall be performed either by such a qualified person or under his supervision.

5.5 Implementation may require more detailed procedural instructions in the format of the using facility.

5.6 In the case of evaluation of a complete system selection of the specific tests to be made should be done cautiously; if the related parameters are not critical in the intended application, then their inclusion may be unjustified. For example, vertical linearity may be irrelevant for a go/no-go test with a flaw gate alarm, while horizontal linearity might be required only for accurate flaw-depth or thickness measurement from the display screen.

5.7 No frequency of system evaluation or calibration is recommended or implied. This is the prerogative of the using parties and is dependent on application, environment, and stability of equipment.

5.8 Certain sections are applicable only to instruments having receiver gain controls calibrated in decibels (dB). While these may sometimes be designated "gain," "attenuator," or "sensitivity" on various instruments, the term "gain controls" will be used in this practice in referring to those which specifically control instrument receiver gain but not including reject, electronic distance-amplitude compensation, or automatic gain control.

5.9 These procedures can generally be applied to any combination of instrument and search unit of the commonly used types and frequencies, and to most straight-beam examination, either contact or immersed. Certain sections are also compatible with angle-beam, wheel, delay-line, and dual-search unit techniques. Their use, however, should be mutually agreed upon and so identified in the test report.

5.10 The validity of the results obtained will depend on the precision of the instrument display readings. This is assumed to be ±0.04 in. (±1 mm), yielding between 1 % and 2 % of full scale (fs) readability for available instrumentation having suitable screen graticules and display sharpness.

6. Procedures for Obtaining Ultrasonic Response Data

6.1 *General:*

6.1.1 A procedure, using this document as a guide, should be prepared for each specific type of instrument or system to be evaluated. For each procedure determine from the requesting documents the instrument examination range to be evaluated, select the appropriate search unit, fixtures, and test blocks, and establish the required display conditions. Unless otherwise required, mid-range values are suggested for most panel controls and "reject" must be off unless specifically desired to be evaluated. It may be desirable to vary the instrument controls from these initial values. If so, it is important to observe and report any anomalous effects on the parameters being evaluated when the controls are so varied.

6.1.2 When a procedure requires a change in receiver gain by the use of a calibrated control, it is assumed that those which increase sensitivity with higher panel readings are designated "gain" and those which decrease sensitivity with higher readings are designated "attenuation." Fine (reference) gain controls, when available, are sometimes not calibrated in decibels and increase sensitivity with clockwise rotation.

6.1.3 Although the procedures in this practice do not describe the use of electronic distance-amplitude compensation, its use is not precluded. If it is used to affect any one or combination of characteristics, measured under this document, then all characteristics shall be evaluated with the same level of compensation as was used on any one, and this level should be referenced in the report. If desired by the using parties, a dual set of test data may be made both with and without distance-amplitude compensation.

6.1.4 If the display screen does not provide a suitable internal graticule, and deflection measurements are being made, fix the eye relative to the external scale to minimize parallax. This practice assumes reading precision of within 2 % of full scale. If, for any reason, this is not feasible for the system under test, estimate the probable accuracy and include this in the report. Readability can sometimes be improved by the use of an external scale attached to the display screen having 50 or 100 divisions for full scale.

6.1.5 For instruments that provide digital readout of signal amplitude, the manufacturer's specified accuracy, if available, shall be noted in the report.

6.1.6 When tests are being done by the contact method, position the search unit securely and make certain that couplant changes are not measurably affecting the results. Refer also to Practice E114.

6.1.7 When using the immersion method, allow adequate time for thermal stabilization; remove bubbles and particles from search unit and test surfaces; maintain the search-unit manipulator and test blocks in stable positions.

6.2 *Horizontal Limit and Linearity:*

6.2.1 *Significance—* Horizontal limit and linearity have significance when determination of depth of a discontinuity is required. A specified minimum trace length is usually necessary to obtain the horizontal readability desired. Nonlinearity of sweep trace may affect accuracy of flaw depth or thickness determination made directly from the display screen.

6.2.2 *Apparatus—*A test block is required that will give several (preferably eleven) noninterfering multiple back reflections for the sweep range and other test conditions of interest (see Fig. 1). Any block having good ultrasonic transmittivity, flat parallel faces, and a thickness of about one tenth of the specified sweep range will usually be adequate. The aluminum blocks shown in Table 1 will be satisfactory for mid-range frequencies and sweep settings on most instruments when the beam is directed through the thickness *T*. For other test frequencies or very large search units, different block dimensions or other block designs may be required to eliminate interferences. The couplant system used, either contact or immersed, must provide stable indications during the measurements. A horizontal scale permitting reading accuracy as specified in 6.1.4 is required or, if provided, digital readout of depth indication may be used.

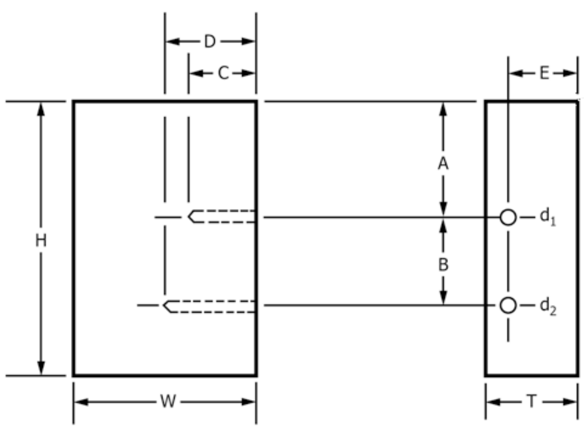
NOTE 1—An encapsulated transducer-targets assembly may be used for this purpose.

6.2.3 *Procedure—*Couple the appropriate block to the search unit so that the sound beam does not intercept any test holes. Adjust the instrument gain, sweep-delay, and sweep-length controls to display eleven noninterfering back reflections. Set the amplitude of each back reflection at 50 % fs before measurement of its position. Further adjust the sweep controls (range, centering, or delay) to position the leading edge of the third and ninth back reflections at the 20 % and 80 % scale divisions respectively (with each set in turn at 50 % fs). After the third and ninth back reflections are positioned accurately on the 20 % and 80 % divisions as described, read and record the scale positions of each other multiple. Alternatively, if sweep-delay is not available, position the second and eighth back reflections at the 20 % and 80 % scale divisions respectively; read and record the scale positions of the initial pulse start and of the remaining multiples. To calibrate the digital readout of horizontal position on instruments so equipped this procedure will require positioning a "gate" to provide an indication from each desired reflection.

NOTE 2—Either more or fewer reflections can be used by suitably modifying the procedure. For example, six back reflections may be used if interference echoes are obtained with eleven, in which case the second back reflection is positioned at the 20 % scale division and the fifth back reflection at the 80 % scale division. Measurement of the horizontal position of each multiple echo, should be made at the same amplitude on the leading edge of the indication. Any specific value may be selected if it is used consistently. Typically used values are baseline break, half amplitude, or signal peak.

6.2.4 *Interpretation of Data:*

6.2.4.1 Horizontal limit is given by the maximum available trace length falling within the display graticule lines or the



Material: 7075T6 aluminum
Plug drilled holes with water-insoluble plastic.

FIG. 1 Suggested Test Blocks for Evaluation of Horizontal and Vertical Linearity

TABLE 1 Linearity Test Block Dimensions

	Table of Dimensions			
	US Customary Block (in.)		Metric Block (mm)	
	Dimension	Tolerance	Dimension	Tolerance
A	1.25	0.05	32	1
B	1.00	0.05	25	1
C	0.75	0.05	19	1
D	1.00	0.05	25	1
E	0.75	0.05	19	1
H	3.00	0.05	75	1
T	1.00	0.01	25	0.2
W	2.00	0.05	50	1
d_1 and d_2	0.047 dia.	0.005	1.2 dia.	0.1
All surfaces:				
Flatness	...	0.001	...	0.02
Parallelism	...	0.001	...	0.02
Finish	63 μ in. or smoother		1.5 μm or smoother	

corresponding digital output limits expressed in linear units (inches or millimetres). Unless otherwise noted, this is also assumed to represent 100 % fs. Failure to obtain full-scale deflection may indicate an equipment malfunction. If an equipment malfunction is found to be the case, the instrument shall be repaired before continuing the evaluation.

6.2.4.2 Linearity test results may be presented in tabular form or, preferably, plotted in the manner shown in Fig. 2. The deviation is given by the displacement (in % full scale) from the straight line through the set-up points representing ideal linearity. For the test point shown (sixth multiple at 55 % fs) the error is 5 % fs. Maximum nonlinearity is given by the "worst case" test point. Linear range is given by the set of contiguous points falling entirely within a specified tolerance.

6.3 *Vertical Limit and Linearity:*

6.3.1 *Significance*— Vertical limit and linearity have significance when echo signal amplitudes are to be determined from the display screen or corresponding analog or digital output signals, and are to be used for evaluation of discontinuities or acceptance criteria. A specified minimum trace deflection or

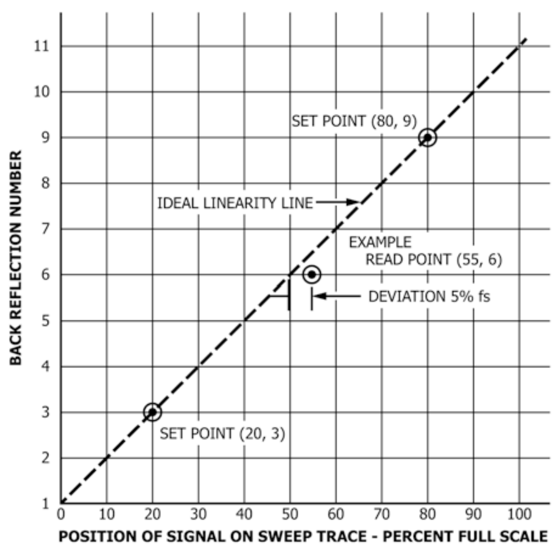


FIG. 2 Example of Data Plot for Determination of Horizontal Linearity

digital equivalent and linearity limit may be required to achieve the desired amplitude accuracy. For other situations they may not be important, for example, go/no-go examinations with flaw alarms or evaluation by comparison with a reference level using calibrated gain controls. This practice describes both the two-signal ratio technique (Method A) and the input/output attenuator technique (Method B). Both methods assume that the test indications used for measurement are free of interferences resulting from nearby signals such as the initial pulse, interface echo, or adjacent multiples. If linearity is of concern under such conditions, for example for near-surface signals, it may be evaluated by the procedure in 6.4.3. Method A (ratio technique) will disclose only nonlinearity that occurs in the instrument circuitry between the gain controls being used to set the amplitudes and the display. Method B (input/output technique) evaluates the entire receiver/display system at constant gain as established initially by the panel controls. Because of this and other differences, the two methods may not give identical results for linearity range. Further, Method A may not disclose certain types of nonlinear response shown by Method B.

6.3.2 *Method A:*

6.3.2.1 *Apparatus*—This method is only applicable when a calibrated external attenuator, as described in 6.3.3.1 for Method B is not available. A test block is required that produces two noninterfering signals having an amplitude ratio of 2 to 1. These are compared over the usable screen height as the instrument gain is changed. The two amplitudes will be referred to as H_A and H_B ($H_A > H_B$). The two signals may occur in either screen order and do not have to be successive if part of a multiple-echo pattern. Unless otherwise specified in the requesting document, any test block that will produce such signals at the nominal test settings specified can be used. For many commonly used search units and test conditions, the test block shown in Fig. 1 will usually be satisfactory when the beam is directed along the *H* dimension toward the two holes. The method is applicable to either contact or immersion tests; however, if a choice exists, the latter may be preferable for ease of set-up and coupling stability.

NOTE 3—An encapsulated transducer-targets assembly may be used for this purpose.

6.3.2.2 *Procedure*—To obtain test data, position the search unit so that two echo signals are obtained having amplitudes in the ratio of about 2 to 1. Determine that there is sufficient range in the gain controls to vary H_A (the larger) from 10 % fs to 100 % fs. Manipulate the search unit and adjust the instrument controls until H_A and H_B meet the conditions in Table 2. The preferred values are desired because the data may be most easily presented and evaluated. However, positioning difficulties or lack of a fine gain or pulse-length control may not permit obtaining the exact values. When optimum set-up conditions are established, secure the search unit in place, observing the precautions noted in 6.1. Adjust the gain controls in steps so that H_A is set in increments of 10 % or less from 10 % fs to 100 % fs. Read and record the values of H_A and H_B within the accuracies prescribed in 6.1.4.

NOTE 4—To better define the response characteristic, particularly near the upper and lower limits, additional readings may be taken at smaller gain increments.

6.3.2.3 *Interpretation of Data*—Vertical limit is given by the maximum vertical deflection (baseline to peak for video and peak to peak for rf) within the usable graticule or digital output range that can be obtained from a large reflector (for example, the test block surfaces) as the gain is increased. Report this in linear units (inches or millimetres) and note equivalent graticule divisions. Unless otherwise stated, this is assumed to represent 100 % fs. Failure to obtain full-scale deflection may indicate an equipment malfunction. If this is found to be the case, the instrument shall be repaired before continuing the evaluation. Linearity test data may be reported in tabular form or preferably presented graphically. Unless otherwise specified in the requesting document, vertical linearity range should be determined graphically using the method shown in Fig. 3. If the preferred set-up condition (H_A = 60 % fs, H_B = 30 % fs) is established initially, the test results may be plotted directly on the scales shown. The limit lines provide a graduated tolerance for H_B of ±1 graph division starting at the set-up point (to provide for reading error) to ±6 divisions at the extremes. Ideal linearity is defined by a straight line extending from the origin through any set-up point to full scale. The linear range is determined by interconnecting adjacent data points and noting the first locations above and below set-up intersecting the limit lines. The upper linearity limit is given by the corresponding value for H_A and the lower limit by that for H_B. If the preferred set-up values were not obtained, a new linearity line and corresponding limits shall be constructed following the same approach.

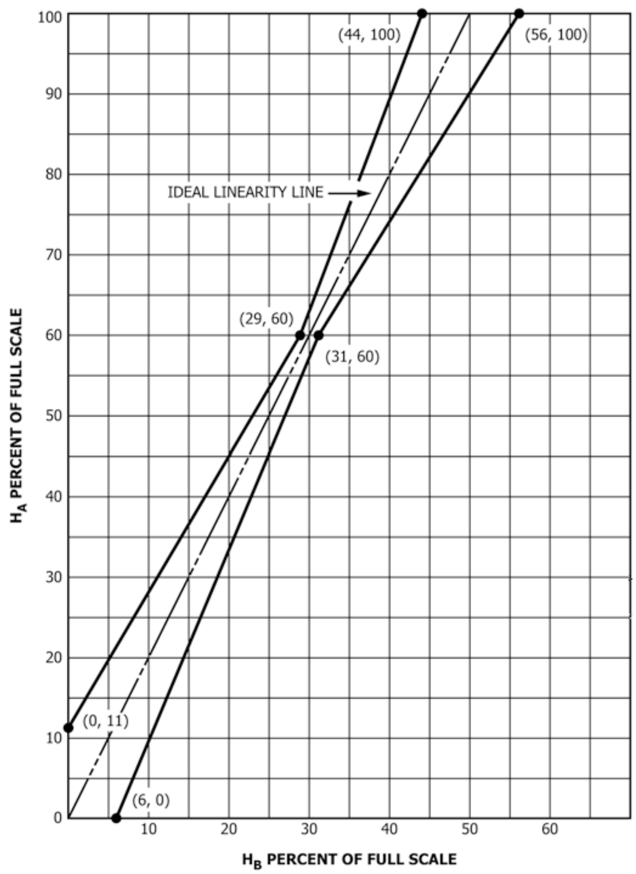


FIG. 3 Data Plot for Determination of Vertical Linearity Range by Method A (Ratio Technique)

TABLE 2 Vertical Linearity Range by Method A Using Two-Signal (Ratio) Technique with Initial Values for H_A and H_B Giving Ratios of 1.8 to 2.2

NOTE 1—Preferred setup values permit determination of vertical linearity range directly from the data plot of Fig. 3.

H_A % Full Scale	H_B % Full Scale
Preferred Values	
60	30
Acceptable	
65	30–36
64	29–36
63	29–35
62	28–34
61	27–34
60	27–33
59	27–33
58	26–32
57	26–32
56	25–31
55	25–31

NOTE 5—If the requesting document specifies that the test results be presented in ratio form (that is, H_A/H_B versus H_A) the necessary values can be calculated from the tabular data and presented in any format specified. To establish linearity limits the desired tolerances must also be stated.

NOTE 6—If the instrument graticule cannot be read directly in % of full scale, the recorded values of H_A and H_B should be converted to percentages of full scale before plotting. If that is not done, new coordinates with appropriate scale and limit lines must be constructed.

6.3.3 *Method B:*

6.3.3.1 *Apparatus*—This method requires the use of an auxiliary external-step attenuator meeting the following minimum specifications which are usually certified by the supplier:

Frequency range	dc to 100 MHz
Attenuation	0 to 80 dB in 1-dB steps
Impedance	50 or 75 Ω
Accuracy	±0.2 dB per 20-dB step

The instrument must be operable in a through-transmission mode with the attenuator inserted between the source of the received signal and the receiver input jack as shown in Fig. 4. Either single-search-unit or the alternative two-search-unit configuration can be used. The attenuator should be connected to the receiver input with a coaxial cable having the same impedance as the attenuator and the terminator. However, negligible error will result if short lengths, that is 6 ft (1.8 m) or less, of commonly used low-capacitance cables are used at mid-range test frequencies. The terminator should be a shielded, noninductive resistor preferably mounted in a coaxial connector. Refer to Note 7 regarding termination errors. In the single-search-unit configuration the pulser is shunted by the attenuator input. Therefore, to isolate the pulser and protect the attenuator if its input rating is exceeded, a dropping resistor may be desirable. If the two-search-unit arrangement is used, no further isolation is required. The path length provided by the test medium shall be adequate to separate the initial pulse (or any instrument cross-talk) from the desired signal, usually that from the first back reflection or interface echo (single-search-unit method) or the first transmitted signal (two-search-unit method). For most test situations a total material path of 2 in. (50 mm) of water or 6 in. (150 mm) of metal such as aluminum will be satisfactory.

NOTE 7—It is assumed that, as is typical of most commercial instruments when operated in the through-transmission mode, the receiver input impedance is large (at least ten times) compared with that of the attenuator. This can usually be determined from the manual or from the manufacturer, and the terminator suitably adjusted. However, when there is a question, a minimum of one 20-dB step should always be left in the attenuator, and terminator errors will be negligible. Proper operation of the attenuator can be checked by determining that any combination of steps having an equivalent value, produces the same signal change. For example, an increase of attenuation from 20 dB to 26 dB should produce the same display change as the increase from 30 dB to 36 dB.

6.3.3.2 *Procedure*—With approximately 30 dB of attenuation in the external attenuator, adjust the instrument sweep and gain controls to produce a center screen deflection of 50 % fs within readability tolerance (that is, 2 % fs or better). Decrease the external attenuation in 1-dB steps until full-scale deflection is reached and record the signal amplitude for each step in

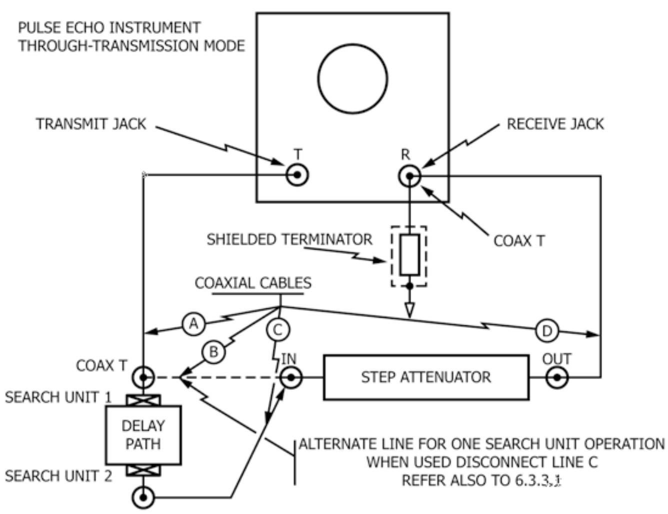


FIG. 4 Recommended System Configuration for Determination of Vertical Linearity (Method B) and Gain Control Calibration

percent of full scale. Reset the external attenuator to again give 50 % fs and increase the external attenuation in 2-dB steps for five steps, and then in 4-dB steps thereafter until the signal essentially disappears; record signal amplitudes for each step.

NOTE 8—Smaller attenuation increments may be used to better define the linearity response. Optional values are given in Table 3.

6.3.3.3 *Interpretation of Data*—Deviations from ideal linearity may be determined either by comparison with tabular values or graphically. Vertical linear range can then be established for any specified deviation, usually stated in percent of full scale. This practice, unless modified by the requesting document, prescribes a tolerance of ±5 % fs in determining upper and lower linearity limits. In addition ±1 % fs is allowed for reading error. To use the tabular method, subtract the amplitude readings obtained for each step from that for the appropriate attenuator step as given in Table 3. The difference (which may be either positive or negative) is the deviation from ideal linearity in percent of full scale. The linear range extends from the lowest to the highest values of sequential amplitudes all falling within prescribed limits. Graphic methods require either logarithmic scales or inverse log calculations to give a straight linearity plot. The preferred format that is convenient to use is shown in Fig. 5. Deviation from ideal linearity can be read directly in percent of full scale, and vertical linearity range established by the limit lines shown. Other limit lines for any specified tolerances may be constructed in a similar manner.

6.4 *Resolution:*

6.4.1 *Significance*—Depth resolution has significance when it is important to identify and quantify reflectors positioned closely together along the depth axis whether they are internal discontinuities or a discontinuity and a boundary. This procedure is concerned with entry and back surface resolution only. Since vertical linearity of signals within interference regions (for example, near surface indications) may sometimes be required, provision is also made for checking this. Resolution, as determined by this practice, includes the combined effects of instrument, search unit, and interconnects and is therefore a system check for the specific components and test conditions used.

6.4.2 *Apparatus*—Select test blocks that provide metal distances corresponding to the resolution range and hole diameters specified in the requesting document or periodic checking procedure for the specific system or type of instrument to be checked. For comparative evaluations blocks may be of any agreed-on material; however, if values for specific test applications are desired, the blocks shall be made from material having ultrasonic properties similar to that to be examined. Specimen characteristics such as metallurgical structure, contour, surface condition, and dimensions can significantly affect results. Further, search unit, test frequency, and operating conditions are major factors. Many types of test blocks have been used for resolution measurements including (*1*) aluminum alloy standard reference blocks as specified in Practice E127, (*2*) steel or other metal-alloy reference blocks made in accordance with Practice E428, (*3*) various commercially available "resolution blocks" having a multiplicity of test holes, notches, etc., and (*4*) special designs meeting user/supplier requirements. Use of ASTM-type aluminum reference blocks is

TABLE 3 Determination of Vertical Linearity Range by Method B Using Input/Output Technique with External Attenuator

Vertical Signal Amplitude versus Relative Attenuation							
Decreasing External Attenuation				Increasing External Attenuation			
−dB	H_R[A] % fs	H_T[B] % fs	$H_R - H_T$ % fs	+dB	H_R % fs	H_T % fs	$H_R - H_T$ % fs
0	50	50	0	0	50	50	0
0.5[C]		53		1[C]		45	
1.0		56		2		40	
1.5[C]		59		3[C]		35	
2.0		63		4		32	
2.5[C]		67		5[C]		28	
3.0		71		6		25	
3.5[C]		75		7[C]		22	
4.0		79		8		20	
4.5[C]		84		9[C]		18	
5.0		89		10		16	
5.5[C]		94		12[C]		13	
6.0		100		14		10	
6.5[D]		106		16[C]		8	
7.0[D]		112		18		6	
7.5[D]		119		20[C]		5	
8.0[D]		126		22		4	
...		...		24[C]		3	
...		...		26		2.5	
...		...		28[C]		2	
...		...		30		1.5	
...		...		32[C]		1.2	
...		...		34		1.0	

[A] H_R Read value of vertical indication from test fixture.
[B] H_T Theoretical value for ideal linear response.
[C] Suggested optional attenuator increments.
[D] Increments possibly required for full-scale deflection.

recommended for determination of entry-surface resolution whenever applicable, for example, comparative tests or aluminum products examination. No equivalent blocks are presently available for far-surface resolution tests. When both entry and far-surface resolution must be determined for specific materials, hole sizes, and test distances, one or more special test blocks are usually required. When feasible, it may be desirable to have all the required test holes in a single block for ease of set-up and test. A suggested configuration is shown in Fig. 6.

6.4.3 *Procedure*—Determine from the requesting document the blocks, frequency, search unit, and test conditions required. Select the block with the test hole that establishes the test sensitivity to be used, usually that needed to produce 80 % fs amplitude for the longest metal distance. Using this block, adjust the instrument controls to set the system sensitivity to the specified level without excessive loss of resolution. To obtain optimum sensitivity/resolution performance, adjustment of pulse length as well as one or more gain controls will frequently be necessary. If an immersion test, make certain that the search unit is positioned laterally for maximum hole-signal amplitude and aligned for interface perpendicularity. Except for interface peaking, no lower gain may be used thereafter, although higher may be required as described. Resolution, either entry or far surface, is determined as follows. Using the established sensitivity, reposition the search unit over each specified hole in turn to optimize the indication, again making certain that the interface signal is maximized by alignment of the search unit (at reduced sensitivity if necessary). If the indication from any required test hole does not peak at 80 % fs or more, increase the sensitivity as needed until it does so. Unless otherwise stated, a hole is considered to be resolved under these conditions if its indication is clearly separated from the adjacent interface indication down to at least 20 % fs and there are no residual indications greater than 20 % fs throughout the test region when the search unit is repositioned to eliminate the test hole signal. These conditions are illustrated in Fig. 7. When this cannot be done because of restricted block dimensions, use a similar type block having a significantly longer metal path. If neither method can be used, estimate the residual noise immediately adjacent to the hole signal and note this limitation in the test report. If linearity within the near surface region must also be determined, for example, to evaluate in the receiver recovery zone as shown in Fig. 8, proceed as follows: Adjust the instrument controls so that the resolved signal amplitude is 80 % fs; then reduce the sensitivity in small increments using a calibrated gain control until its amplitude is 20 % fs. Record the change of gain (in decibels) required. Appendix X1 provides dimensions for a specific design of a Fig. 6 type block which is intended to meet the resolution test requirements specified in a number of commonly used material inspection standards.

NOTE 9—Although the above procedure does not describe the use of electronic distance-amplitude compensation, its use is not precluded and substantially improved effective resolution may result. However, if used, the procedures of 6.1.3 shall be followed.

6.4.4 *Interpretation of Data*—Resolution, either entry or far-surface, is given by the metal distance from the test-hole bottom to the appropriate surface, the hole diameter, and the reference used to establish test sensitivity (if other than the specified resolution block hole). Nonlinearity of the response within the resolved test range is expressed by the difference in decibels between 12 dB and the incremental gain change required to reduce the test hole indication from 80 % fs to 20 %

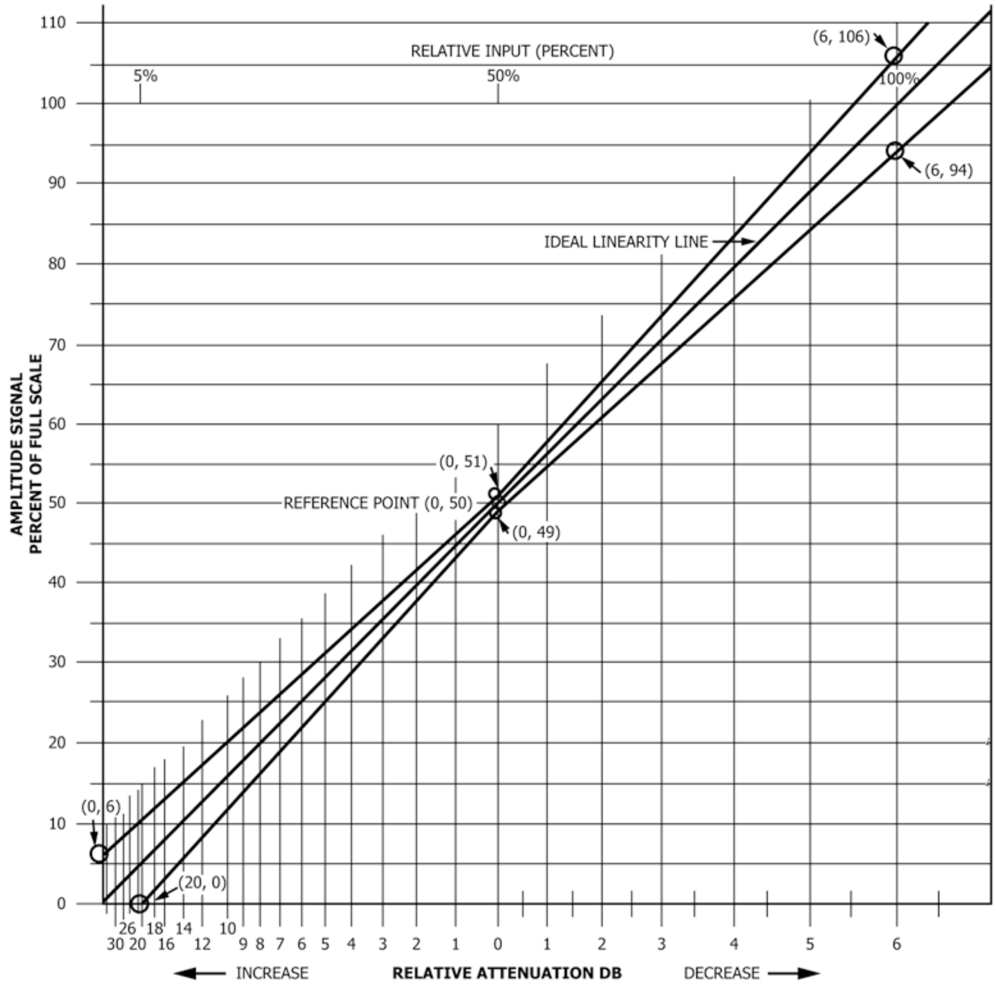
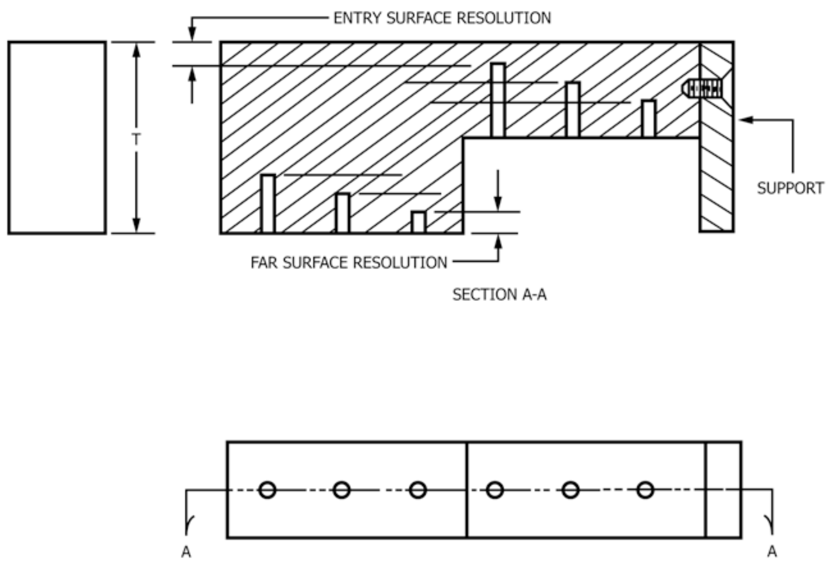


FIG. 5 Data Plot for Determination of Vertical Linearity by Method B (Input/Output Technique)



NOTE 1—Material, thickness *T*, hole diameters, and surface roughness as specified by test requirements.
NOTE 2—One or more flat bottom holes spaced to avoid interferences and with ends plugged.

FIG. 6 Suggested Configuration for Resolution Test Block

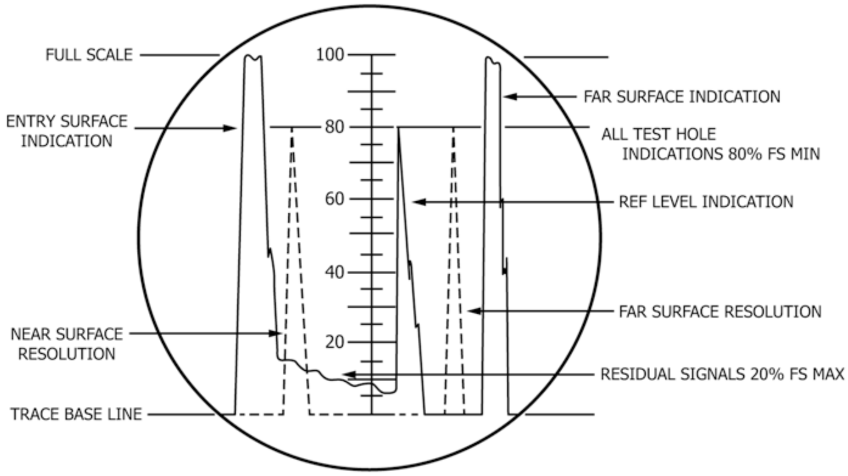


FIG. 7 Typical Display Response for Determination of Near-Surface and Far-Surface Resolution

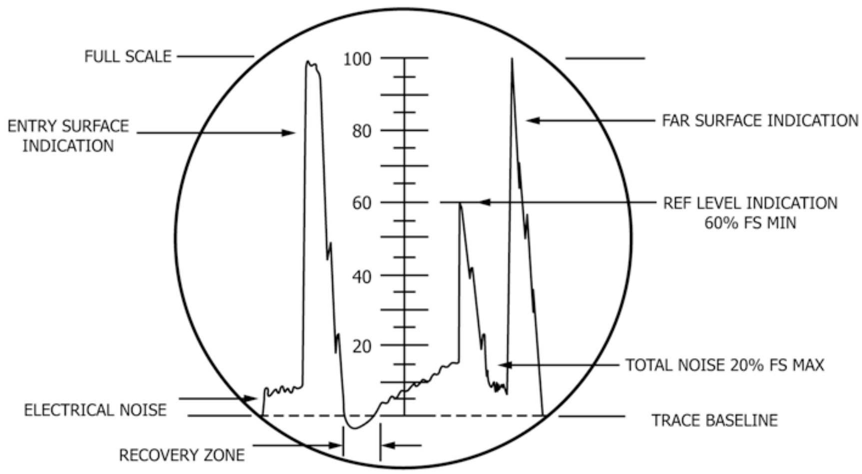


FIG. 8 Typical Display Response for Determination of Sensitivity and Noise

fs. The report shall also fully identify the test blocks, specific holes, search unit, and test parameters used.

6.5 *Sensitivity and Noise:*

6.5.1 *Significance*—Sensitivity is a measure of a test system's ability to detect discontinuities producing relatively low-amplitude signals because of their size, geometry, or distance. Noise can limit detectability of discontinuities by masking their indications. Its source may be electrical or acoustic, and if due to indications from the material structure, represents a possible limitation of the test method rather than the instrumentation. Generally, sensitivity, resolution, and signal-to-noise ratio are interdependent and shall be evaluated under similar test conditions.

6.5.2 *Apparatus*—Unless otherwise specified in the requesting document, use test blocks selected from an area/amplitude set of aluminum alloy standard reference blocks meeting the requirements of Practice E127. As discussed in 6.4.2, such blocks can provide a comparative basis for evaluating system performance, but if data are required for other specific materials or test conditions, appropriate special blocks must be used. Where E127-type aluminum blocks are applicable, the following selection is suggested for determining the probably minimum size detectable hole:

Test Frequency, MHz	0.4 to 1.5	1.0 to 2.5	2.0 to 10.0
Block designation	5-0300 to 8-0300	2-0300 to 6-0300	1-0300 to 5-0300

6.5.3 *Procedure*—With the instrument sensitivity at maximum, determine the smallest hole size that will give an indication having an amplitude of at least 60 % fs and baseline noise in the test region of no more than 20 % fs. A typical instrument display is shown in Fig. 8. If the dimensions of the test block allow, move the search unit just away from the hole and determine that the noise at the same location as the indication does not exceed 20 % fs. Otherwise follow the procedure of 6.4.3 for residual-noise determination. Record the block number, noise level, and signal amplitude if greater than 60 % fs. If the noise at maximum sensitivity exceeds 20 % fs, reduce the gain until 20 % fs is obtained and determine the smallest hole that will then produce a 60 % fs or greater indication. Record the block number, noise level, signal amplitude, and reduced gain (in decibels). If the indication from the smallest available hole exceeds 100 % fs, use the gain control to lower the hole indication to 60 % fs and record the remaining available gain (in decibels) that does not cause the noise to exceed 20 % fs.

NOTE 10—If this requires the use of an uncalibrated gain control, use the instrument's calibrated attenuator if available, or a suitable external attenuator to determine the applicable gain reduction factors (in decibels) using the gain control positions as determined above and a suitable reflector indication on the screen. Refer to 6.6.3 for use of external attenuator to calibrate a gain control.

NOTE 11—Since this is a systems check, the indicated noise will be a summation of both instrument electrical noise and acoustical noise from search unit, couplant, and test material. If separation of the electrical component is required, note first the noise to the left of the initial pulse. Remove the search unit and make certain that the noise remains about the same. If not, lower the pulse repetition rate until the noise to the left of the initial pulse, both with or without the search unit connected, is the same. Record this noise as the average electrical noise.

6.5.4 *Interpretation of Data:*

6.5.4.1 Sensitivity is expressed by stating the specific hole size/test distance that produces the required 60 % fs signal at a 3-to-1 or greater signal-to-noise ratio, and the gain control settings needed; that is, either maximum gain or remaining available gain up to that which gives 20 % fs or less noise.

6.5.4.2 System noise is given either by the peak noise amplitude at maximum sensitivity if less than 20 % fs, or by the gain reduction in decibels of the noise below the smallest available hole that gives 60 % fs or greater indication. If so specified, both total noise and electrical noise shall be reported.

6.6 *Accuracy of Calibrated Gain Controls:*

6.6.1 *Significance*—When quantitative measurement of signal amplitudes are to be made by comparison against a reference indication, the use of accurately calibrated gain controls may be desirable or necessary, particularly when the amplitude ratio differs significantly from unity. For this procedure, it is assumed that the controls are calibrated in conventional decibel units. Refer to 6.1.2 regarding gain control nomenclature.

6.6.2 *Apparatus*—A precision external attenuator, terminating resistor, and test set-up similar to that described in 6.3.3.1 are required. The attenuator must have a range at least equal to that being checked plus the additional needed to bring the test signal on scale at highest instrument sensitivity specified.

NOTE 12—The maximum range for any single panel control function is usually 60 dB or less. This method is not recommended for checking larger ranges, obtained for example, by sequential use of more than one control, since cross-talk may become a problem.

NOTE 13—A test precision of 1.0 dB is assumed to be adequate and obtainable. Greater precision requires either smaller attenuator steps or use of correction factors for the display screen readings. Refer also to Note 7.

6.6.3 *Procedure*—Select a test system configuration that will produce a stable, on-screen, mid-scale indication when the instrument controls are set for the minimum desired sensitivity and the external attenuator has sufficient available attenuation to equal the desired test range. Use the fine-gain control when available, or pulse-length adjustment to set the reference indication precisely at the 60 % fs graticule line. Record the settings of the external attenuator and the calibrated controls, noting whether they represent decibel gain or decibel attenuation. Increase the instrument gain in the smallest available calibrated increment, and add sufficient external attenuation to return the test indication as closely as possible to the 60 % fs reference line. With 1.0 dB or smaller attenuator increments available, the adjusted amplitude should always lie between 56 % fs and 64 % fs when the correct step is used. Record the new gain control and external attenuator settings. Repeat the procedure until the full range of the relevant instrument control has been checked.

6.6.4 *Interpretation of Data*—Unless otherwise instructed by the requesting document, use the results as follows: For each control range tested, tabulate the readings of the control against the incremental attenuation added externally. This value is given by subtracting the initial external attenuation from each subsequent reading of total attenuation. The total error for any range is then the difference (in decibels) between the panel value of control range and that determined by the external attenuator. Report the error, if any, in terms of total deviation per 20 dB of control range and also for the full range of any control of greater range.

NOTE 14—The data obtained can be used to determine the error for any intermediate steps if required.

6.7 *Thickness Gages*

6.7.1 *Significance*—Analog, digital or variable frequency thickness gages are used to measure a variety of materials by the application of a search unit to one side of a material with parallel, or nearly-parallel, front and back surfaces. Since the range of thicknesses to be measured for various applications is large and the degree of coverage required varies with the intended usage, choice of transducer size, frequency, damping and focal characteristics also may vary over a fairly wide range. Also, since the output of thickness measuring instruments is dependent on the travel time of a signal from front to back surfaces the results are dependent upon the propagation velocity of a wave of a given frequency, or range of frequencies, in the particular material being examined. This requires standardization for any material examination using samples of known thickness of material identical in ultrasonic velocity and shape to the test material. These variables are not considered in the procedures outlined below which are intended to evaluate the accuracy of the instrument itself under controlled conditions.

6.7.2 *Apparatus*—A set of samples of known thicknesses in the range, or ranges, of interest is required. For each thickness range to be measured, three test samples of known thickness are required. One of these should be near the lower thickness limit of the range, one near the higher limit, and one near the center of the range. Thickness of the samples shall be measured by mechanical or optical instruments calibrated on blocks certified to at least twice the required evaluation accuracy. The surface finish of the samples must be adequate to provide good coupling. The material of the samples shall be sufficiently free of internal and external defects to prevent confusion of the test results. The choice of contact or immersion technique for the evaluation is determined by the user or contracting agency. The characteristics of the transducer or transducers to be employed are determined by the material thicknesses of interest and the selected technique.

6.7.3 *Procedure*

6.7.3.1 *For Instruments with both Low and High (or Intercept and Slope) Controls*—For each range to be examined, the instrument should be adjusted to produce output readings of the desired accuracy when coupled to the high and low samples. Once set these readings must be repeatable without instrument readjustment. The near-midrange sample is then checked with no further instrument adjustment and the output reading recorded and compared to the known measured value for that sample.

6.7.3.2 *For Instruments with Only One Control (Velocity or Slope)*—For each range to be examined, the instrument should be adjusted to produce an output reading of the desired accuracy when coupled to one of the test samples. The other two are then checked with no further instrument adjustment and the output readings recorded and compared to the known measured values for those samples.

6.7.4 *Interpretation of Data*—Deviation of the measured thickness divided by the known sample thickness is of course a measure of the percentage accuracy of the instrument at that point. This figure shall be recorded and reported in the evaluation report (see Section 7). In the case that more data points are required, additional samples of known intermediate thickness are necessary.

7. Report

7.1 The requesting document should fully define the extent of the written report required. As a minimum this may involve only confirmation of specified performance or the results of the parameters evaluated. A comprehensive written report shall include all relevant information in sufficient detail so that the tests could be duplicated later if desired.

7.2 The following format is recommended for a report requiring complete documentation of the tests:

7.2.1 Instrument—name, model, modules, and serial numbers

7.2.2 Description of Apparatus used for each test including: Search Units—type, catalog number, frequency, size (serial number when available)

Interconnecting Devices—cables, search tubes

Test Fixtures—positioner, bridge, clamps

Couplant

Test Blocks—specify by ASTM nomenclature, or if special, source, drawing number or complete description (material, size and location of test holes, geometry, dimensions, surface)

External Attenuator—type, impedance, precision, and terminator

7.2.3 Method of each test including:

Contact or Immersion technique

Water Path where applicable

Control Settings relevant to tests—including internal controls when used

Test Frequency—Tuned or Wide Band

7.2.4 Test Results of each instrument characteristic evaluated

8. Precision and Bias

8.1 No ASTM round-robin tests have been made to determine the repeatability of readings or the precision and bias obtainable with the procedures described. The assumed reading precision (2 % of full scale) stated in 5.10 is considered to be obtainable in practice and adequate for the purposes of this standard.

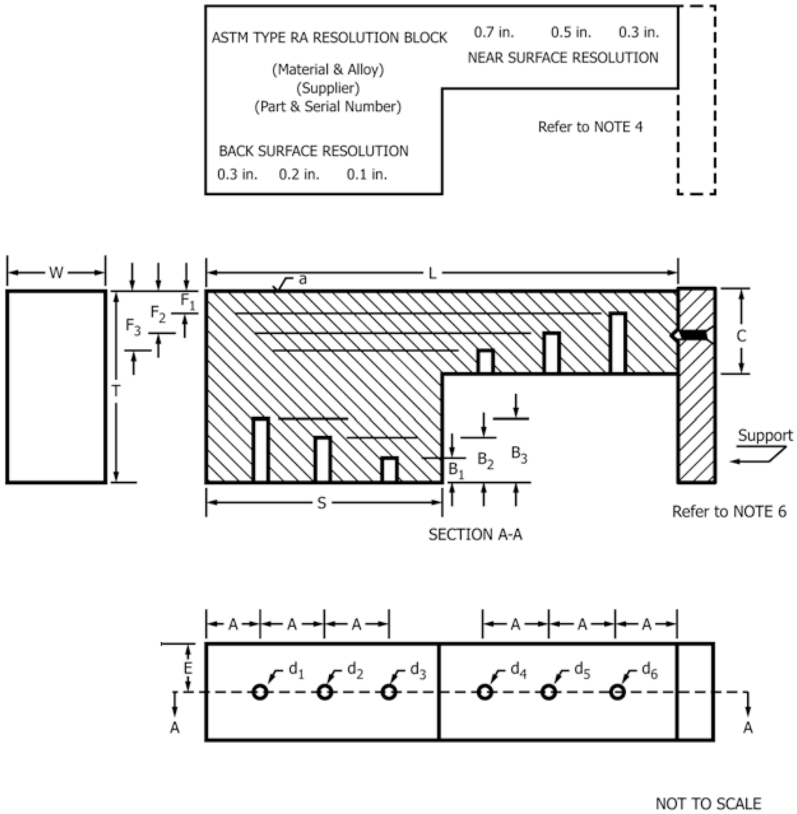
9. Keywords

9.1 evaluation of pulse-echo examination systems; evaluation of ultrasonic pulse-echo instruments; nondestructive testing; performance characteristics of ultrasonic examination instruments ; performance characteristics of ultrasonic examination systems; pulse-echo examination instruments; pulse-echo examination systems; ultrasonic examination instruments; ultrasonic examination systems

APPENDIX

(Nonmandatory Information)

X1. SPECIFIC DESIGN FOR FIGURE 6 RESOLUTION TEST BLOCK



NOTE 1—Material to be as specified.

NOTE 2—Surface finish: "a" Ra 32 µin. (0.8 µm) max. Other surfaces Ra 63 µin. (1.6 µm) max.

NOTE 3—3⁄64 in. (1.2 mm) diameter flat-bottom holes (d_1...d_6) to be perpendicular to faces within 1°; FB surfaces to be finished smooth to full diameter; holes to be cleaned, dried, and plugged leaving air gap of 0.04 in. (1 mm) min.

NOTE 4—Legends as shown (or metric equivalents) to be engraved 1⁄8 in. (3 mm) high at approximate locations indicated.

NOTE 5—Block finish to be anodizing or plating as specified.

NOTE 6—Location for optional end support; attachment entry into block not to exceed 1⁄4 in. (6 mm).

	Table of Dimensions			
	US Customary Block (in.)		Metric Block (mm)	
Legend	Dimension	Tolerance	Dimension	Tolerance
L	8.00	0.02	200.0	0.5
T	3.30	0.02	82.5	0.5
W	2.00	0.02	50.0	0.5
C	1.00	0.02	25.0	0.5
S	4.00	0.02	100.0	0.5
A	1.00	0.02	25.0	0.5
E	1.00	0.02	25.0	0.5
d_1...d_6	0.0469	0.0005	1.2	0.01
B_1	0.100	0.005	2.5	0.1
B_2	0.200	0.005	5.0	0.1
B_3	0.300	0.005	7.5	0.1
F_1	0.300	0.005	7.5	0.1
F_2	0.500	0.005	12.5	0.1
F_3	0.700	0.005	17.5	0.1

FIG. X1.1 Type RA Resolution Test Block

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STANDARD PRACTICE FOR MEASURING THICKNESS BY MANUAL ULTRASONIC PULSE-ECHO CONTACT METHOD

(19) SE-797/SE-797M

(Identical with ASTM Specification E797/E797M-15.)

Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method

1. Scope

1.1 This practice provides guidelines for measuring the thickness of materials using the contact pulse-echo method at temperatures not to exceed 93°C [200°F].

1.2 This practice is applicable to any material in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back reflections can be obtained and resolved.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E494 Practice for Measuring Ultrasonic Velocity in Materials

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

Nondestructive Testing Handbook, 2nd Edition, Vol 7

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Aerospace Industries Association Document:*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

2.4 *ISO Standard:*

ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

3. Terminology

3.1 *Definitions: Definitions*—For definitions of terms used in this practice, refer to Terminology E1316.

4. Summary of Practice

4.1 Thickness (T), when measured by the pulse-echo ultrasonic method, is a product of the velocity of sound in the material and one half the transit time (round trip) through the material.

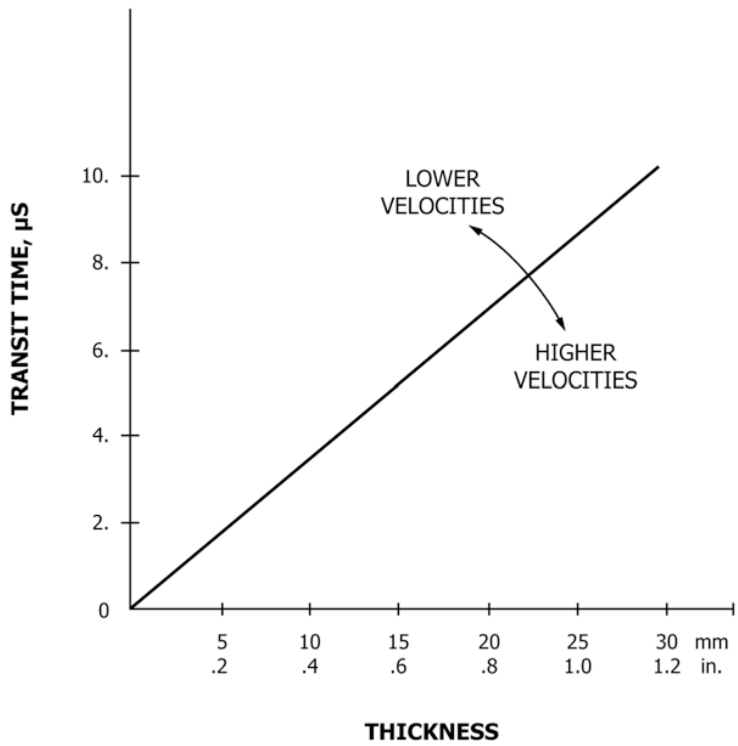
$$T = \frac{Vt}{2}$$

where:

T = thickness,
V = velocity, and
t = transit time.

4.2 The pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse through the part.

4.3 The velocity in the material being examined is a function of the physical properties of the material. It is usually assumed to be a constant for a given class of materials. Its approximate value can be obtained from Table X3.1 in Practice



NOTE 1—Slope of velocity conversion line is approximately that of steel.

FIG. 1 Transit Time/Thickness Relationship

E494 or from the *Nondestructive Testing Handbook*, or it can be determined empirically.

4.4 One or more reference blocks are required having known velocity, or of the same material to be examined, and having thicknesses accurately measured and in the range of thicknesses to be measured. It is generally desirable that the thicknesses be "round numbers" rather than miscellaneous odd values. One block should have a thickness value near the maximum of the range of interest and another block near the minimum thickness.

4.5 The display element (A-scan display, meter, or digital display) of the instrument must be adjusted to present convenient values of thickness dependent on the range being used. The control for this function may have different names on different instruments, including *range, sweep, material standardize*, or *velocity*.

4.6 The timing circuits in different instruments use various conversion schemes. A common method is the so-called time/analog conversion in which the time measured by the instrument is converted into a proportional d-c voltage which is then applied to the readout device. Another technique uses a very high-frequency oscillator that is modulated or gated by the appropriate echo indications, the output being used either directly to suitable digital readouts or converted to a voltage for other presentation. A relationship of transit time versus thickness is shown graphically in Fig. 1.

5. Significance and Use

5.1 The techniques described provide indirect measurement of thickness of sections of materials not exceeding temperatures of 93°C [200°F]. Measurements are made from one side of the object, without requiring access to the rear surface.

5.2 Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion.

5.3 Recommendations for determining the capabilities and limitations of ultrasonic thickness gages for specific applications can be found in the cited references.[1,2]

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized

[1] Bosselaar, H., and Goosens, J.C.J., "Method to Evaluate Direct-Reading Ultrasonic Pulse-Echo Thickness Meters," *Materials Evaluation,* March 1971, pp. 45–50.

[2] Fowler, K.A., Elfbaum, G.M., Husarek, V., and Castel, J., "Applications of Precision Ultrasonic Thickness Gaging," *Proceedings of the Eighth World Conference on Nondestructive Testing,* Cannes, France, Sept. 6–11, 1976, Paper 3F.5.

NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be specified in the contractual agreement.

7. Apparatus

7.1 *Instruments*—Thickness-measurement instruments are divided into three groups: (*1*) Flaw detectors with an A-scan display readout, (*2*) Flaw detectors with an A-scan display and direct thickness readout, and (*3*) Direct thickness readout.

7.1.1 Flaw detectors with A-scan display readouts display time/amplitude information. Thickness determinations are made by reading the distance between the zero-corrected initial pulse and first-returned echo (back reflection), or between multiple-back reflection echoes, on a standardized base line of the A-scan display. The base line of the A-scan display should be adjusted for the desired thickness increments.

7.1.2 Flaw detectors with numeric readout are a combination pulse ultrasound flaw detection instrument with an A-scan display and additional circuitry that provides digital thickness information. The material thickness can be electronically measured and presented on a digital readout. The A-scan display provides a check on the validity of the electronic measurement by revealing measurement variables, such as internal discontinuities, or echo-strength variations, which might result in inaccurate readings.

7.1.3 Thickness readout instruments are modified versions of the pulse-echo instrument. The elapsed time between the initial pulse and the first echo or between multiple echoes is converted into a meter or digital readout. The instruments are designed for measurement and direct numerical readout of specific ranges of thickness and materials.

7.2 *Search Units*—Most pulse-echo type search units (straight-beam contact, delay line, and dual element) are applicable if flaw detector instruments are used. If a thickness readout instrument has the capability to read thin sections, a highly damped, high-frequency search unit is generally used. High-frequency (10 MHz or higher) delay line search units are generally required for thicknesses less than about 0.6 mm [0.025 in.]. Measurements of materials at high temperatures require search units specially designed for the application. When dual element search units are used, their inherent nonlinearity usually requires special corrections for thin sections. (See Fig. 2.) For optimum performance, it is often necessary that the instrument and search units be matched.

7.3 *Standardization Blocks*—The general requirements for appropriate standardization blocks are given in 4.4, 8.1.3, 8.2.2.1, 8.3.2, and 8.4.3. Multi-step blocks that may be useful for these standardization procedures are described in Appendix X1 (Figs. X1.1 and X1.2).

8. Standardization of Apparatus

8.1 *Case I—Direct Contact, Single-Element Search Unit:*

8.1.1 *Conditions*—The display start is synchronized to the initial pulse. All display elements are linear. Full thickness is displayed on the A-scan display.

8.1.2 Under these conditions, we can assume that the velocity conversion line effectively pivots about the origin (Fig. 1). It may be necessary to subtract the wear-plate time, requiring minor use of delay control. It is recommended that standardization blocks providing a minimum of two thicknesses that span the thickness range be used to check the full-range accuracy.

8.1.3 Place the search unit on a standardization block of known thickness with suitable couplant and adjust the instrument controls (material standardization, range, sweep, or velocity) until the display presents the appropriate thickness reading.

8.1.4 The readings should then be checked and adjusted on standardization blocks with thickness of lesser value to improve the overall accuracy of the system.

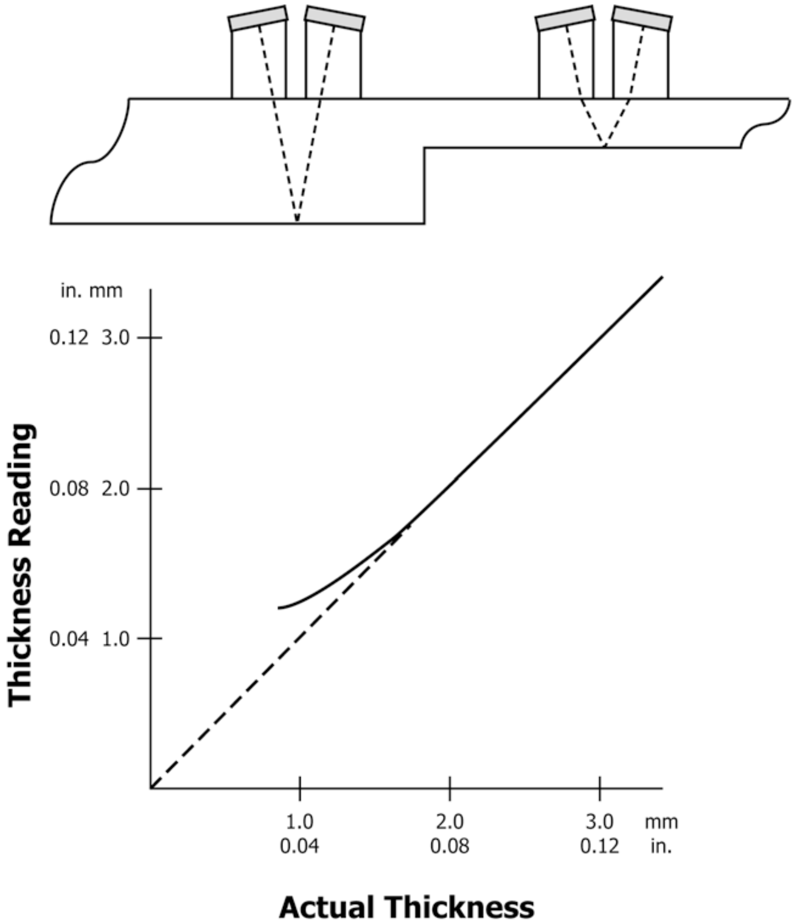
8.2 *Case II—Delay Line Single-Element Search Unit:*

8.2.1 *Conditions*—When using this search unit, it is necessary that the equipment be capable of correcting for the time during which the sound passes through the delay line so that the end of the delay can be made to coincide with zero thickness. This requires a so-called "delay" control in the instrument or automatic electronic sensing of zero thickness.

8.2.2 In most instruments, if the material standardize circuit was previously adjusted for a given material velocity, the delay control should be adjusted until a correct thickness reading is obtained on the instrument. However, if the instrument must be completely standardized with the delay line search unit, the following technique is recommended:

8.2.2.1 Use at least two standardization blocks. One should have a thickness near the maximum of the range to be measured and the other block near the minimum thickness. For convenience, it is desirable that the thickness should be "round numbers" so that the difference between them also has a convenient "round number" value.

8.2.2.2 Place the search unit sequentially on one and then the other block, and obtain both readings. The difference between these two readings should be calculated. If the reading thickness difference is less than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material standardize control to expand the thickness range. If the reading thickness difference is greater than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material standardize control to decrease the thickness range. A certain amount of over correction



(*a*) Proportional sound path increases with decrease in thickness.
(*b*) Typical reading error values.

FIG. 2 Dual Transducer Nonlinearity

is usually recommended. Reposition the search unit sequentially on both blocks, and note the reading differences while making additional appropriate corrections. When the reading thickness differential equals the actual thickness differential, the material thickness range is correctly adjusted. A single adjustment of the delay control should then permit correct readings at both the high and low end of the thickness range.

8.2.3 An alternative technique for delay line search units is a variation of that described in 8.2.2. A series of sequential adjustments are made, using the "delay" control to provide correct readings on the thinner standardization block and the "range" control to correct the readings on the thicker block. Moderate over-correction is sometimes useful. When both readings are "correct" the instrument is adjusted properly.

8.3 *Case III—Dual Search Units:*

8.3.1 The method described in 8.2 (Case II) is also suitable for equipment using dual search units in the thicker ranges, above 3 mm [0.125 in.]. However, below those values there is an inherent error due to the Vee path that the sound beam travels. The transit time is no longer linearly proportional to thickness, and the condition deteriorates toward the low thickness end of the range. The variation is also shown schematically in Fig. 2(*a*). Typical error values are shown in Fig. 2(*b*).

8.3.2 If measurements are to be made over a very limited range near the thin end of the scale, it is possible to standardize the instrument with the technique in Case II using appropriate thin standardization blocks. This will produce a correction curve that is approximately correct over that limited range. Note that it will be substantially in error at thicker measurements.

8.3.3 If a wide range of thicknesses is to be measured, it may be more suitable to standardize as in Case II using standardization blocks at the high end of the range and perhaps halfway toward the low end. Following this, empirical corrections can be established for the very thin end of the range.

8.3.4 For a direct-reading panel-type meter display, it is convenient to build these corrections into the display as a nonlinear function.

8.4 *Case IV—Thick Sections:*

8.4.1 *Conditions*—For use when a high degree of accuracy is required for thick sections.

8.4.2 Direct contact search unit and initial pulse synchronization are used. The display start is delayed as described in 8.4.4. All display elements should be linear. Incremental thickness is displayed on the A-scan display.

8.4.3 Basic standardization of the sweep will be made as described in Case I. The standardization block chosen for this standardization should have a thickness that will permit standardizing the full-sweep distance to adequate accuracy, that is, about 10 mm [0.4 in.] or 25 mm [1.0 in.] full scale.

8.4.4 After basic standardization, the sweep must be delayed. For instance, if the nominal part thickness is expected to be from 50 to 60 mm [2.0 to 2.4 in.], and the basic standardization block is 10 mm [0.4 in.], and the incremental thickness displayed will also be from 50 to 60 mm [2.0 to 2.4 in.], the following steps are required. Adjust the delay control so that the fifth back echo of the basic standardization block, equivalent to 50 mm [2.0 in.], is aligned with the 0 reference on the A-scan display. The sixth back echo should then occur at the right edge of the standardized sweep.

8.4.5 This standardization can be checked on a known block of the approximate total thickness.

8.4.6 The reading obtained on the unknown specimen must be added to the value delayed off screen. For example, if the reading is 4 mm [0.16 in.], the total thickness will be 54 mm [2.16 in.].

9. Technical Hazards

9.1 Dual search units may also be used effectively with rough surface conditions. In this case, only the first returned echo, such as from the bottom of a pit, is used in the measurement. Generally, a localized scanning search is made to detect the minimum remaining wall.

9.2 *Material Properties*—The instrument should be standardized on a material having the same acoustic velocity and attenuation as the material to be measured. Where possible, standardization should be confirmed by direct dimensional measurement of the material to be examined.

9.3 *Scanning*—The maximum speed of scanning should be stated in the procedure. Material conditions, type of equipment, and operator capabilities may require slower scanning.

9.4 *Geometry:*

9.4.1 Highest accuracy can be obtained from materials with parallel or concentric surfaces. In many cases, it is possible to obtain measurements from materials with nonparallel surfaces. However, the accuracy of the reading may be limited and the reading obtained is generally that of the thinnest portion of the section being interrogated by the sound beam at a given instant.

9.4.2 Relatively small-diameter curves often require special techniques and equipment. When small diameters are to be measured, special procedures including additional specimens may be required to ensure accuracy of setup and readout.

9.5 High-temperature materials, up to about 540°C [1000°F], can be measured with specially designed instruments with high-temperature compensation, search unit assemblies, and couplants. Normalization of apparent thickness readings for elevated temperatures is required. A rule of thumb often used is as follows: The apparent thickness reading obtained from steel walls having elevated temperatures is high (too thick) by a factor of about 1 % per 55°C [100°F]. Thus, if the instrument was standardized on a piece of similar material at 20°C [68°F], and if the reading was obtained with a surface temperature of 460°C [860°F], the apparent reading should be reduced by 8 %. This correction is an average one for many types of steel. Other corrections would have to be determined empirically for other materials.

9.6 *Instrument*—Time-base linearity is required so that a change in the thickness of material will produce a corresponding change of indicated thickness. If a CRT is used as a readout, its horizontal linearity can be checked by using Practice E317.

9.7 *Back Reflection Wavetrain*—Direct-thickness readout instruments read the thickness at the first half cycle of the wavetrain that exceeds a set amplitude and a fixed time. If the amplitude of the back reflection from the measured material is different from the amplitude of the back reflection from the standardization blocks, the thickness readout may read to a different half cycle in the wavetrain, thereby producing an error. This may be reduced by:

9.7.1 Using reference blocks having attenuation characteristics equal to those in the measured material or adjusting back reflection amplitude to be equal for both the standardizing blocks and measured material.

9.7.2 Using an instrument with automatic gain control to produce a constant amplitude back reflection.

9.8 *Readouts*—A-scan displays are recommended where reflecting surfaces are rough, pitted, or corroded.

9.8.1 Direct-thickness readout, without an A-scan display, presents hazards of misadjustment and misreading under certain test conditions, especially thin sections, rough corroded surfaces, and rapidly changing thickness ranges.

9.9 *Reference Standards*—Greater accuracy can be obtained when the equipment is standardized on areas of known thickness of the material to be measured.

9.10 Variations in echo signal strength may produce an error equivalent to one or more half-cycles of the RF frequency, dependent on instrumentation characteristics.

10. Procedure Requirements

10.1 In developing the detailed procedure, the following items should be considered:

10.1.1 Instrument manufacturer's operating instructions
10.1.2 Scope of materials/objects to be measured
10.1.3 Applicability, accuracy requirements
10.1.4 Definitions
10.1.5 Requirements
10.1.5.1 Personnel
10.1.5.2 Equipment
10.1.5.3 Procedure qualification
10.1.5.4 Training or certification levels
10.1.6 Procedure
10.1.6.1 Measurement conditions
10.1.6.2 Surface preparation and couplant
10.1.6.3 Standardization and allowable tolerances
10.1.6.4 Scanning parameters

10.1.7 Report
10.1.7.1 Procedure used
10.1.7.2 Standardization record
10.1.7.3 Measurement record

11. Report

11.1 Record the following information at the time of the measurements and include it in the report:
11.1.1 Examination procedure.
11.1.1.1 Type of instrument.
11.1.1.2 Standardization blocks, size and material type.
11.1.1.3 Size, frequency, and type of search unit.
11.1.1.4 Scanning method.
11.1.2 Results.
11.1.2.1 Maximum and minimum thickness measurements.
11.1.2.2 Location of measurements.
11.1.3 Personnel data, certification level.

12. Keywords

12.1 contact examination; nondestructive testing; pulse-echo; thickness measurement; ultrasonics

APPENDIX

(Nonmandatory Information)

X1. Typical Multi-Step Thickness Gage Reference Blocks

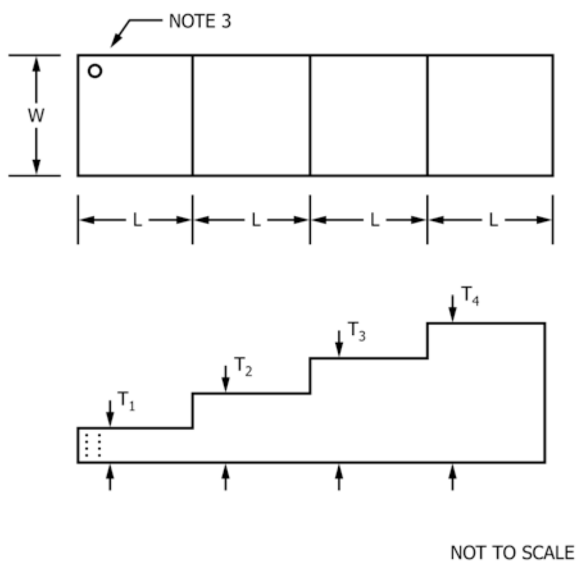


TABLE OF DIMENSIONS

	U.S. Customary Block, in.		Metric Block 4A, mm		Metric Block 4B, mm	
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T_1	0.250	0.001	6.25	0.02	5.00	0.02
T_2	0.500	0.001	12.50	0.02	10.00	0.02
T_3	0.750	0.001	18.75	0.02	15.00	0.02
T_4	1.000	0.001	25.00	0.02	20.00	0.02
L	0.75	0.02	20.0	0.5	20.0	0.5
W	0.75	0.05	20.0	1.0	20.0	1.0

NOTE 1—Material to be as specified.

NOTE 2—Surface finish: "T" faces Ra 0.8 µm [32 µin.] max. Other surfaces Ra 1.6 µm [63 µin.] max.

NOTE 3—Location for optional 1.5 mm [1⁄16 in.] diameter through hole used for block support during plating; center 1.5 mm [1⁄16 in.] from block edges.

NOTE 4—All "T" dimensions to be after any required plating or anodizing.

NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.5 mm [0.020 in.].

FIG. X1.1 Typical Four-Step Thickness Reference Blocks

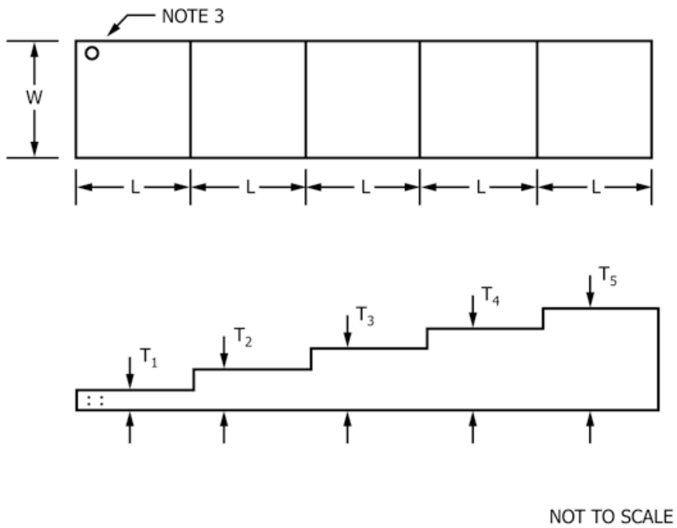


TABLE OF DIMENSIONS

	U.S. Customary Block, in.		Metric Block 5A, mm		Metric Block 5B, mm	
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T_1	0.100	0.001	2.50	0.02	2.00	0.02
T_2	0.200	0.001	5.00	0.02	4.00	0.02
T_3	0.300	0.001	7.50	0.02	6.00	0.02
T_4	0.400	0.001	10.00	0.02	8.00	0.02
T_5	0.500	0.001	12.50	0.02	10.00	0.02
L	0.75	0.02	20.0	0.5	20.00	0.5
W	0.75	0.05	20.0	1.0	20.00	1.0

NOTE 1—Material to be as specified.

NOTE 2—Surface finish: "T" faces Ra 0.8 µm [32 µin.] max. Other surfaces Ra 1.6 µm [63 µin.] max.

NOTE 3—Location for optional 1.5 mm [1⁄16 in.] diameter through hole used for block support during plating; center 1.5 mm [1⁄16 in.] from block edges.

NOTE 4—All "T" dimensions to be after any required plating or anodizing.

NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.5 mm [0.020 in.].

FIG. X1.2 Typical Five-Step Thickness Reference Blocks

STANDARD GUIDE FOR EVALUATING PERFORMANCE CHARACTERISTICS OF PHASED-ARRAY ULTRASONIC TESTING INSTRUMENTS AND SYSTEMS

SE-2491

(Identical with ASTM Specification E2491-13.)

Standard Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems

1. Scope

1.1 This guide describes procedures for evaluating some performance characteristics of phased-array ultrasonic examination instruments and systems.

1.2 Evaluation of these characteristics is intended to be used for comparing instruments and systems or, by periodic repetition, for detecting long-term changes in the characteristics of a given instrument or system that may be indicative of impending failure, and which, if beyond certain limits, will require corrective maintenance. Instrument characteristics measured in accordance with this guide are expressed in terms that relate to their potential usefulness for ultrasonic examinations. Other electronic instrument characteristics in phased-array units are similar to non-phased-array units and may be measured as described in Guide E1065 or E1324.

1.3 Ultrasonic examination systems using pulsed-wave trains and A-scan presentation (rf or video) may be evaluated.

1.4 This guide establishes no performance limits for examination systems; if such acceptance criteria are required, these must be specified by the using parties. Where acceptance criteria are implied herein they are for example only and are subject to more or less restrictive limits imposed by customer's and end user's controlling documents.

1.5 The specific parameters to be evaluated, conditions and frequency of test, and report data required, must also be determined by the user.

1.6 This guide may be used for the evaluation of a complete examination system, including search unit, instrument, interconnections, scanner fixtures and connected alarm and auxiliary devices, primarily in cases where such a system is used repetitively without change or substitution. This guide is not intended to be used as a substitute for calibration or standardization of an instrument or system to inspect any given material.

1.7 Required test apparatus includes selected test blocks and position encoders in addition to the instrument or system to be evaluated.

1.8 Precautions relating to the applicability of the procedures and interpretation of the results are included.

1.9 Alternate procedures, such as examples described in this document, or others, may only be used with customer approval.

1.10 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E494 Practice for Measuring Ultrasonic Velocity in Materials

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

E1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments

3. Terminology

3.1 Refer to Terminology E1316 for definitions of terms in this guide.

4. Summary of Guide

4.1 Phased-array instruments and systems have similar individual components as are found in traditional ultrasonic systems that are based on single channel or multiplexed pulse-echo units. These include pulsers, receivers, probes and interconnecting cables. The most significant difference is that phased-array systems form the transmitted ultrasonic pulse by constructive phase interference from the wavelets formed off the individually pulsed elements of the phased-array probes.

4.2 Each phased-array probe consists of a series of individually wired elements that are activated separately using a programmable time delay pattern. Varying the number of elements used and the delay time between the pulses to each element allows control of the beam. Depending on the probe design, it is possible to electronically vary the angle (incident or skew), or the focal distance, or the beam dimensions, or a combination of the three. In the receiving mode, acoustic energy is received by the elements and the signals undergo a summation process utilizing the same type of time delay process as was used during transmission.

4.3 The degree of beam steering available is dependent on several parameters including; number of elements, pitch of the element spacing, element dimensions, element array shape, resonant frequency of the elements, the material into which the beam is directed, the minimum delay possible between firing of adjacent pulsers and receivers and the pulser voltage characteristics.

4.4 Pulser and receiver parameters in phased-array systems are generally computer controlled and the received signals are typically displayed on computer monitors via computer data acquisition systems and may be stored to computer files.

4.5 Although most systems use piezo-electric materials for the elements, electro-magnetic acoustic transducer (EMAT) devices have also been designed and built using phased-array instrumentation.

4.6 Most phased array systems can use encoders for automated and semi-automated scanning.

4.7 Side Drilled Holes used as targets in this document should have diameters less than the wavelength of the pulse being assessed and long enough to avoid end effects from causing interfering signals. This will typically be accomplished when the hole diameter is between about 1.5 mm and 2.5 mm and 20 mm to 25 mm in length.

5. Significance and Use

5.1 This guide is intended to evaluate performance assessment of combinations of phased-array probes and instruments. It is not intended to define performance and acceptance criteria, but rather to provide data from which such criteria may be established.

5.2 Recommended procedures described in this guide are intended to provide performance-related measurements that can be reproduced under the specified test conditions using simple targets and the phased-array test system itself. It is intended for phased-array flaw detection instruments operating in the nominal frequency range of 1 MHz to 20 MHz, but the procedures are applicable to measurements on instruments utilizing significantly higher frequency components.

5.3 This guide is not intended for service calibration, or maintenance of circuitry for which the manufacturer's instructions are available.

5.4 Implementation of specific assessments may require more detailed procedural instructions in a format of the using facility.

5.5 The measurement data obtained may be employed by users of this guide to specify, describe, or provide a performance criteria for procurement and quality assurance, or service evaluation of the operating characteristics of phased-array systems.

5.6 Not all assessments described in this guide are applicable to all systems. All or portions of the guide may be used as determined by the user.

6. Procedure

6.1 Procedures for assessment of several parameters in phased-array systems are described in Annexes A1 to A7.

6.1.1 These include; determination of beam profile, beam steering capability, element activity, focusing capability, software calculations (controls and display of received signals), compensation for wedge attenuation, receiver gain linearity.

7. Keywords

7.1 characterization; focal point; phased-array; phased-array probe; sound beam profile; ultrasound

ANNEXES

(Mandatory Information)

A1. DETERMINATION OF PHASED-ARRAY BEAM PROFILE

A1.1 Introduction

A1.1.1 This annex describes procedures to determine beam profiles of phased-array probes. Either immersion or contact probe applications can be addressed using these procedures. However, it should be cautioned that assessments of contact probes may suffer from variability greater than imposed tolerances if proper precautions are not taken to ensure constant coupling conditions.

A1.2 Test Setup

A1.2.1 For single focal laws where the beam is fixed (that is, not used in an electronic or sectorial scan mode) and the probe is used in an immersion setup, the ball-target or hydrophone options described in E1065 may be used. For phased array probes used in a dynamic fashion where several focal laws are used to produce sectorial or electronic scanning it may be possible to make beam-profile assessments with no or little mechanical motion. Where mechanical motion is used it shall be encoded to relate signal time and amplitude to distance moved. Encoder accuracy shall be verified to be within tolerances appropriate for the measurements made. Descriptions made for electronic scan and sectorial scan beam profile assessments will be made for contact probes; however, when assessment in water is required the machined targets may be replaced with rods or balls as appropriate.

A1.2.2 *Linear-Array Probes*—Linear-array probes have an active plane and an inactive or passive plane. Assessment of the beam in the active plane should be made by use of an electronic scan sequence for probes with sufficient number of elements to electronically advance the beam past the targets of interest. For phased array probes using a large portion of the available elements to form the beam the number of remaining elements for the electronic raster may be too small to allow the beam to pass over the target. In this case it will be necessary to have encoded mechanical motion and assess each focal law along the active plane separately.

A1.2.3 Side-drilled holes should be arranged at various depths in a flaw-free sample of the test material in which focal laws have been programmed for. Using the linear scan feature of the phased-array system the beam is passed over the targets at the various depths of interest. The electronic scan is illustrated schematically in Fig. A1.1.

A1.2.4 Data collection of the entire waveform over the range of interest shall be made. The display shall represent amplitude as a color or grayscale. Time or equivalent distance in the test material shall be presented along one axis and distance displaced along the other axis. This is a typical B-scan as illustrated in Fig. A1.2.

A1.2.5 Data display for an electronic scan using a phased-array probe mounted on a wedge can be similarly made using simple orthogonal representation of time versus displacement or it can be angle corrected as illustrated in Fig. A1.3.

A1.2.6 Resolution along the displacement axis will be a function of the step size of the electronic scan or, if the scan uses an encoded mechanical fixture the resolution will be dependent on the encoder step-size used for sampling.

A1.2.7 Resolution along the beam axis will be a function of the intervals between the target paths. For highly focused beams it may be desirable to have small differences between the sound paths to the target paths (for example, 1 mm or 2 mm).

A1.2.8 Beam profiling in the passive plane can also be made. The passive plane in a linear-array probe is perpendicular to the active plane and refers to the plane in which no beam steering is possible by phasing effects. Beam profiling in the passive direction will require mechanical scanning.

A1.2.9 Waveform collection of signals using a combination of electronic scanning in the active plane and encoded mechanical motion in the passive plane provides data that can be projection-corrected to provide beam dimensions in the passive

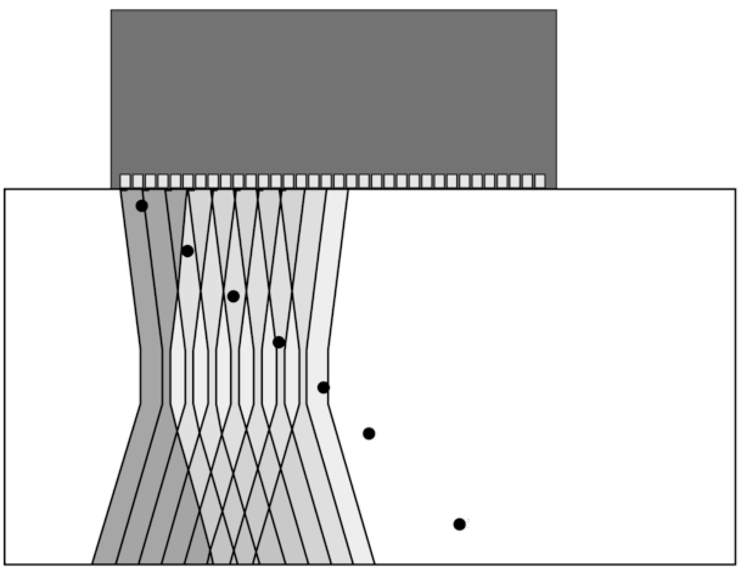


FIG. A1.1 Electronic Scan of Side Drilled Holes

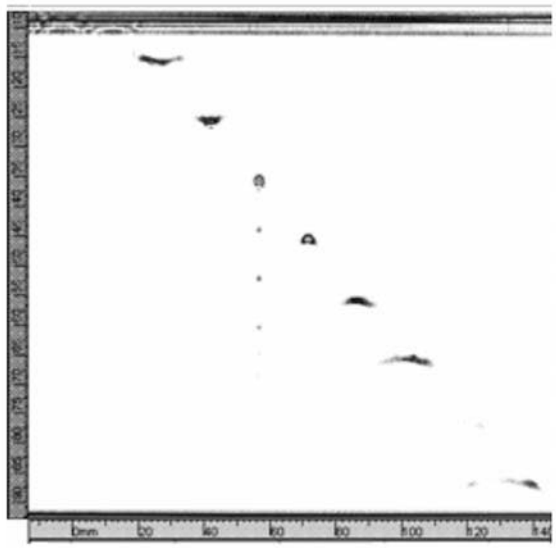


FIG. A1.2 B-Scan Display of Electronic Scan Represented in Fig. A1.1 **(Depth is in the vertical axis and electronic-scan distance is represented along the horizontal axis.)**

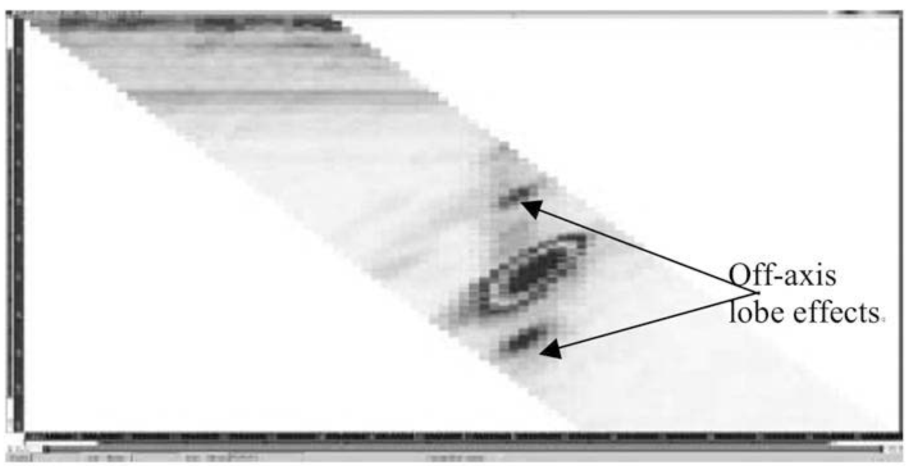


FIG. A1.3 Angle-Corrected B-Scan of a Phased-Array Beam (in Shear Wave Mode) from a Side Drilled Hole (Off-axis lobe effects can be seen in the display.)

plane. Fig. A1.4 illustrates a method for beam assessment in the passive plane. This technique uses a corner reflection from an end-drilled hole at depths established by a series of steps.

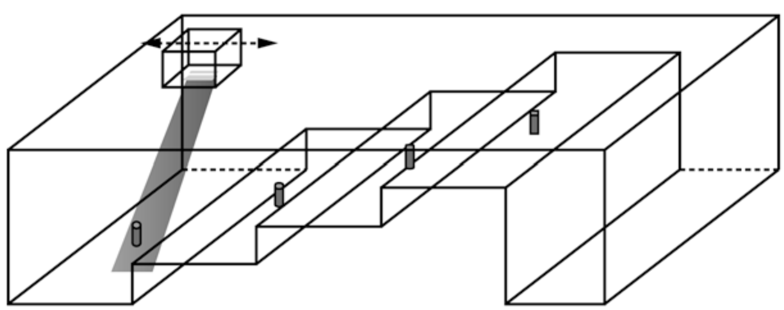


FIG. A1.4 Scanning End-Drilled Holes to Obtain Beam Dimensions in Passive Plane

A1.2.10 Fig. A1.5 illustrates an alternative to the stepped intervals shown in Fig. A1.4. A through hole may be arranged perpendicular to the required refracted angle to provide a continuous transition of path length to the target.

A1.2.11 A projected C-scan can be used to size the beam based on either color or grayscale indicating amplitude drop or a computer display that plots amplitude with respect to displacement. The projected C-scan option is schematically represented in Fig. A1.6.

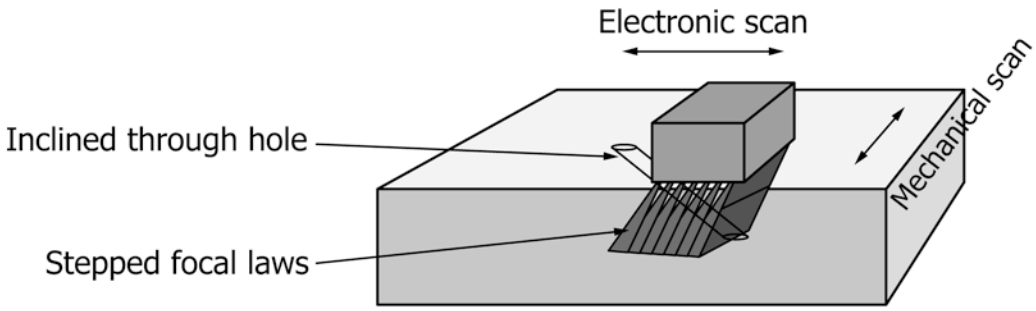


FIG. A1.5 Representation of an Inclined Hole for Beam Characterization in the Passive Plane

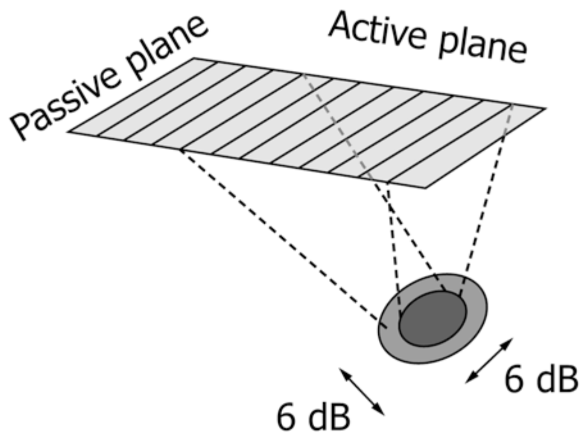


FIG. A1.6 Representation of Projected C-Scan of Corner Effect Scan Seen in Fig. A1.4

A2. DETERMINATION OF PHASED-ARRAY BEAM STEERING LIMITS

A2.1 Introduction

A2.1.1 This annex describes procedures to determine practical limits for beam steering capabilities of a phased-array probe and as such applies to the active plane(s) only. Either immersion or contact probe applications can be addressed using these procedures. However, it should be cautioned that assessments of contact probes may suffer from variability greater than imposed tolerances if proper precautions are not taken to ensure constant coupling conditions.

A2.1.2 Recommended limits to establish the working range of angular sweep of a phased-array probe relate to the divergence of the beam of each element in the probe array. When used in pulse-echo mode the steering limit is considered to be within the 6-dB divergence envelope of the individual elements. It is therefore possible to calculate a theoretical limit based on nominal frequency and manufacturer provided information on the element dimensions. However, several parameters can affect the theoretical calculations. These are primarily related to the nominal frequency of the probe. Some parameters affecting actual frequency include; pulse length, damping, use of a delay-line or refracting wedge and variations in manufacturing processes on thickness lapping and matching layers.

A2.1.3 For the purposes of this procedure, assessment of beam steering capability will be based on a comparison of signal to noise ratios at varying angular displacements. Beam steering capability will also be affected by project requirements of the beam. Applications where focusing is necessary may not achieve the same limits as applications where the beam is not focused as well as steered.

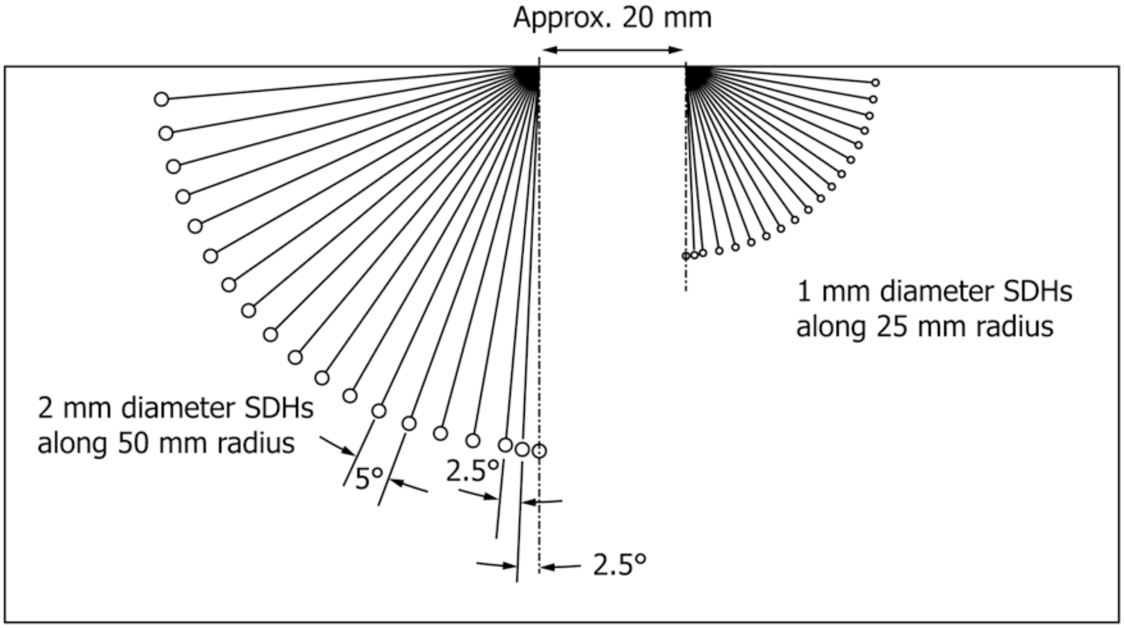
A2.1.4 Steering capability may be specific to a sound path distance, aperture and material.

A2.2 *Test Set-Up*—Configure the probe focal laws for the conditions of the test. This will include immersion or contact, refracting wedge or delay-line, unfocused or a defined focal distance and the test material to be used.

A2.2.1 Prepare a series of side drilled holes in the material to be used for the application at the distance or distances to be used in the application. The side-drilled-hole pattern should be as illustrated in Fig. A2.1. Holes indicated in Fig. A2.1 are at 5° intervals at a 25-mm and 50-mm distance from a center where the probe is located.

A2.2.2 Similar assessments are possible for different applications. When a set of focal laws is arranged to provide resolution in a plane instead of a sound path distance, the plane of interest may be used to assess the steering limits of the beam. The block used for assessment would be arranged with side drilled holes in the plane of interest. Such a plane-specific block is illustrated in Fig. A2.2 where a series of holes is made in a vertical and horizontal plane at a specified distance from the nominal exit point. Side drilled holes may be arranged in other planes (angles) of interest.

A2.2.3 Assessments are made placing the probe such that the center of beam ray enters the block at the indicated centerline. For analysis of a probe where all the elements in a single plane are used without a delay line or refracting wedge the midpoint of the element array shall be aligned with the centerline. For focal laws using only a portion of the total available elements the midpoint of the element aperture shall be aligned with the centerline. When delay lines, refracting wedges or immersion methods are used corrections will be required to compensate for movement of the "apparent" exit point along the block entry surface. When a probe is used in direct contact with a verification block as illustrated in Fig. A2.2 the lack of symmetry either side of the centerline prevents



NOTE 1—Block dimensions 150 by 75 by 25 mm (typical)

FIG. A2.1 Beam Steering Assessment Block—Constant Sound Path

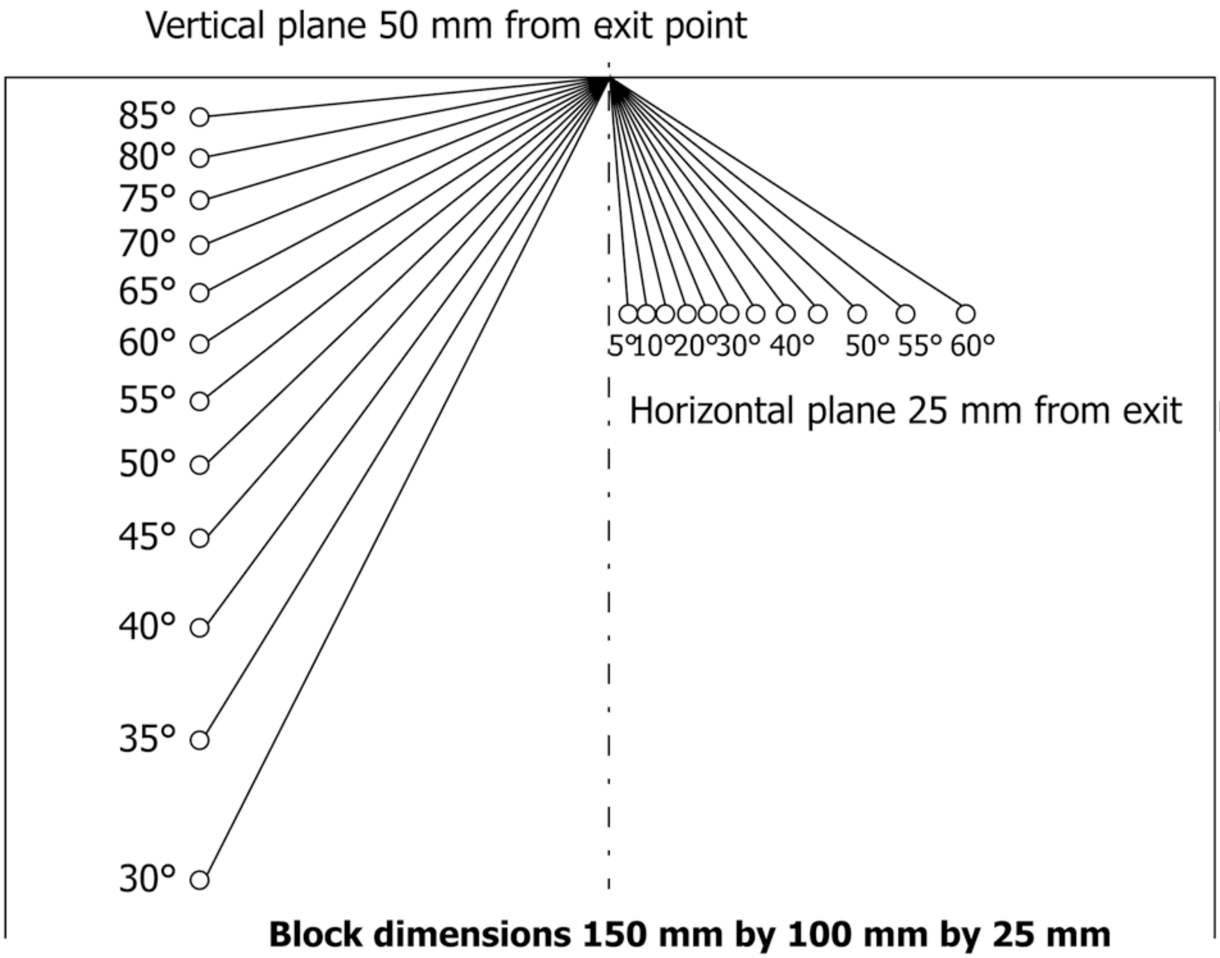


FIG. A2.2 Beam Steering Assessment Block—Single Plane

both positive and negative sweep angles being assessed simultaneously. To assess the sweep limit in the two directions when using this style of block requires that the probe be assessed in one direction first and then rotated 180° and the opposite sweep assessed.

A2.2.4 Angular steps between A-scan samples will have an effect on the perceived sweep limits. A maximum of 1° between S-scan samples is recommended for steering assessment. Angular steps are limited by the system timing-delay capabilities between pulses and element pitch characteristics. Most of the targets illustrated in Fig. A2.1 and Fig. A2.2 are separated by 5°; however, greater or lesser intervals may be used depending on the required resolution.

A2.2.5 Assessment of steering limits shall be made using the dB difference between the maximum and minimum signal amplitudes between two adjacent side drilled holes. For example, when a phased array probe is configured to sweep +45° on a block such as illustrated in Fig. A2.1, the higher of the pair of the SDHs which achieves a 6-dB separation shall be considered the maximum steering capability of the probe configuration.

A2.2.6 Acceptable limits of steering may be indicated by the maximum and minimum angles that can achieve a pre-specified separation between adjacent holes. Depending on the application a 6-dB or 20-dB (or some other value) may be specified as the required separation.

A2.2.7 Steering capabilities may be used as a prerequisite; for example, a phased array system is required to achieve a minimum steering capability for 5° resolution of 2-mm diameter side drilled holes of plus and minus 20° from a nominal mid-angle. Conversely, a system may be limited to S-scans not exceeding the angles assessed to achieve a specified signal separation, for example, –20 dB between 2-mm diameter SDHs separated by 5°.

A2.3 An alternative assessment may use a single SDH at a specified depth or sound path distance. Displaying the A-scan for the maximum and minimum angles used would assess the steering capability by observing the S/N ratio at the peaked response. Steering limit would be a pre-defined S/N ratio being achieved. Caution must be taken when using this method so as to not peak on grating lobe signals. This method will also require confirmation that the SDH is positioned at the calculated refracted angle.

A3. DETERMINATION OF PHASED-ARRAY ELEMENT ACTIVITY

A3.1 Introduction

A3.1.1 This assessment is used to determine that all elements of the phased array probe are active and of uniform acoustic energy. Because, during normal operation in a timed sequence, each of the elements is addressed by a separate pulser and receiver, a method must be used that ensures the electronic performance of the phased-array instrument is identical from element to element and any differences are attributable to the probe itself. To ensure that any variation of element performance is due only to probe construction, a single pulser-receiver channel is selected to address each element.

A3.2 Test Set-Up

A3.2.1 Connect the phased array probe to be tested to the phased-array ultrasonic instrument and remove any delay line or refracting wedge from the probe.

A3.2.2 Acoustically couple the probe to the 25-mm thickness of an IIW (International Institute of Welding) block with a uniform layer of couplant. This may be accomplished by a contact-gap technique such that the probe-to-block interface is under water (to ensure uniform coupling). Alternatively an immersion method using a fixed water path may be used and the water-steel interface signal monitored instead of the steel wall thickness.

A3.2.3 Configure an electronic scan consisting of one element that is stepped along one element at a time for the total number of elements in the array. (This should ensure that the pulser-receiver number 1 is used in each focal law or if the channel is selectable it should be the same channel used for each element). Set the pulser parameters to optimize the response for the nominal frequency of the probe array and establish a pulse-echo response from the block backwall or waterpath to 80 % display height for each element in the probe.

A3.2.4 Observe the A-scan display for each element in the array and record the receiver gain required to achieve the 80 % signal amplitude for each element. Results may be recorded on a table similar to that in Table A3.1.

TABLE A3.1 Probe Element Activity Chart: Enter Receiver Gain for 80 % FSH

Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gain																
Active (⊓) Inactive (x)																

A3.2.5 Note and record any elements that do not provide a backwall or waterpath signal (inactive elements). Results may be recorded on a table similar to that in Table A3.1.

A3.2.6 If a prepackaged program is available for checking element activity, this can be used as an alternative.

A3.2.7 Data collected is used to assess probe uniformity and functionality. Comparison to previous assessments is made using the same instrument settings (including gain) that were saved to file. The receiver gain to provide an 80 % response should be within a range of ±2 dB of any previous assessments and within ±2 dB of each other.

A3.2.8 The total number of inactive elements and number of adjacent inactive elements in a probe should be agreed upon and identified in a written procedure. This number may be different for baseline and in-service verifications. Some phased array probes may have several hundred elements and even new phased-array probes may be found to have inactive elements as a result of manufacturing difficulties ensuring the electrical connections to elements with dimensions on the order of a fraction of a millimetre.

A3.2.9 The number of inactive elements allowed should be based on performance of other capabilities such as focusing and steering limits of the focal laws being used. No simple rule for the number of inactive elements can be made for all phased-array probes. Typically, if more than 25 % of the elements in a probe are inactive, sensitivity and steering capabilities may be compromised. Similarly, the number of adjacent elements allowed to be inactive should be determined by the steering and electronic raster resolution required by the application.

A3.2.10 Stability of coupling is essential for the comparison assessment. If using a contact method and the assessment of elements produces signals outside the ±2-dB range the coupling should be checked and the test run again. If still outside the acceptable range the probe should be removed from service and corrected prior to further use. The test using a fixed water path to a water/steel interface will reduce coupling variations.

A3.2.11 Prior to removing the probe from service the cable used for the test should be exchanged with another cable, when possible, to verify that the inactive elements are not due to a bad cable.

A3.2.12 Cable continuity adapters can be made that allow the multi-strand connectors to be tested independently. These adaptors can be connected to the phased array instrument directly to verify that all output channels are active or they can be connected to the probe-end of the cable to indicate the continuity of the individual co-axial connectors in the interconnecting cable. Fig. A3.1 illustrates an example of a display used to identify inactive channels in a phased array instrument or cable.

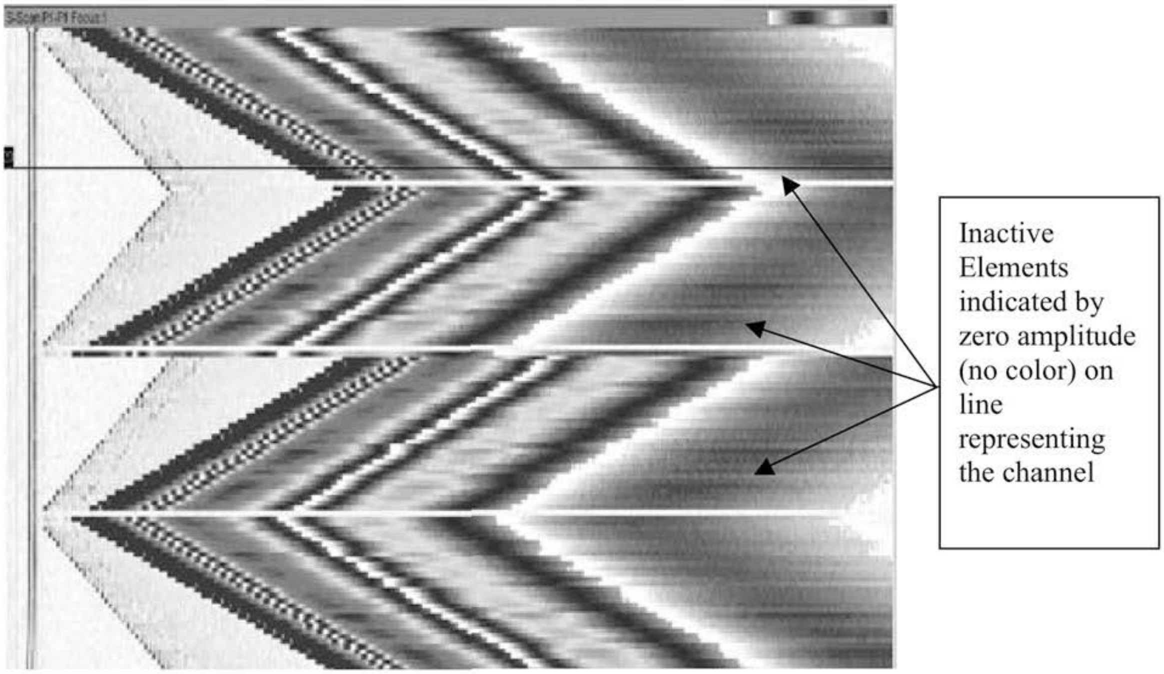


FIG. A3.1 Continuity Display for Phased-Array Instrument or Cable

A4. ASSESSMENT OF PHASED-ARRAY FOCUSING ABILITY

A4.1 Introduction

A4.1.1 Focusing of ultrasonic beams is based on well known principles. However, unlike single element probes, phased-array systems can be configured to focus over a range of sound paths and in both transmit and receive modes. Effectiveness of the focusing algorithms can be assessed by determining the beam response dimensions. This is similar to the beam profiling described in Annex A1. Limits of focusing are intrinsic in the probe parameters and subject to the minimum timing-delay capabilities of the phased-array ultrasonic instrument.

A4.2 Test Set-Up

A4.2.1 Configure the phased-array system for the focusing focal laws to be assessed and acoustically couple the phased-array probe to a block with inclined side drilled holes as illustrated in Fig. A1.1. Compression modes with or without a delay-line and shear modes using a refracting wedge can be assessed by this method.

A4.2.2 Focusing at a single refracted angle is assessed by this method. Where several angles are used it will be necessary to assess the focusing ability for each angle separately.

A4.2.3 Using either an electronic scan or encoded mechanical scan in the plane of interest, the full waveforms are collected and displayed in a depth corrected B-scan projection image as illustrated in Fig. A4.1.

A4.2.4 Effectiveness of the focusing algorithm is assessed by sizing the diameter of the projected image based on a dB drop from maximum amplitude and comparing that dimension to the actual machined diameter of the side drilled hole.

A4.2.5 Working range of the focusing algorithm may be determined by agreement as to the maximum dimension of the oversizing of the side-drilled hole diameter. For example, if 2-mm diameter SDH's are used and the 6-dB drop is used to gauge diameter from the B-scan, the working range can be defined as the depth or sound-path distance that the B-scan can maintain the 6-dB dimension to less than twice the actual diameter.

A4.2.6 Practical limits for hole diameters and focal spot sizes are required. Practical focal spots for focused beams cannot be made smaller than about 1.5 times the wavelength used. For a 5-MHz compression wave in steel this is about 1.7 mm. The focal spot size is also a function of sound path; the deeper the holes, the weaker the focusing.

A4.2.7 In order that the diameter assessment be meaningful, the sample interval must be small compared to the target assessed. It is recommended that at least four samples per hole diameter be used. For example, for a 2-mm diameter SDH target the sample interval of a mechanized encoded scan should be 0.5 mm or for an electronic scan the step between each focal law should not exceed 0.5 mm (this will be limited by the element pitch of the probe).

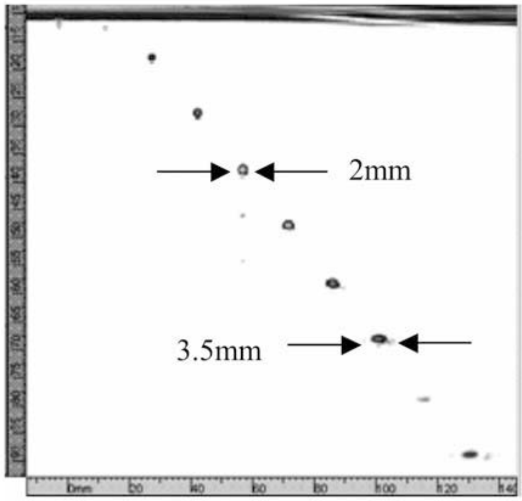


FIG. A4.1 B-Scan Projected Image of Dynamic Depth Focusing Algorithm

A5. ASSESSMENT OF PHASED-ARRAY COMPUTER CONTROL OF PARAMETERS AND DATA DISPLAY

A5.1 Introduction

A5.1.1 Phased-array beam control is based on the Fermat Principle which implies that sound follows the path of least time. This principle is used in ray-tracing of sound paths of transmitted wavefronts from the elements of a phased-array probe to calculate the delays required in the timing electronics to direct a beam to a specified location. Using the Fermat Principle, refracted angles and focal positions are calculated by entering the acoustic velocities of the materials through which the sound propagates. If the material acoustic velocities are accurate then the calculated position of the beam will also be accurate. Accuracy of the calculations is therefore a function of several variables including; acoustic velocity of the materials used, dimensions of the probe components (element size, dominant frequency, divergence, travel distance in the delay line or wedge) and pulser timing accuracy to affect the necessary phase interference patterns. If all the variables are accurately entered in the appropriate equations the beam should be accurately positioned. In a computer controlled system the only evidence available to the operator is the data display. This provides a coordinate system that positions the response from a target in two or three dimensions. Relating the theoretical plotted position on the display to actual known positions of specific targets is the only effective method of assessing the validity of the combination of variables and the computer algorithms for the display.

A5.2 Test Set-Up

A5.2.1 Using a contact linear phased-array probe, nominally 5 MHz and having at least 16 elements with a pitch not greater than 1 mm, configure the software for two separate S-scans, one at ±30° with a focal distance of 25 mm in steel (that is, focused at a sound path of 25 mm in steel), the other at ±30° with a focal distance of 50 mm in steel (that is, focused at a sound path of 50 mm in steel). For both sets of focal laws program an angular step interval of 0.5° and all focal laws shall use 16 adjacent elements.

A5.2.2 Ensure that the digitizing frequency for data collection is at least 80 MHz.

A5.2.3 Prepare a series of side drilled holes in a steel block that has acoustic velocity determined in accordance with E494. This velocity value will be used in the focal laws.

A5.2.4 Acoustically couple and align the probe on the block illustrated in Fig. A2.1 such that the centre of the element array aligns with the centerline of the hole pattern.

A5.2.5 Scan and save the S-scan for the 25-mm focal distance.

A5.2.6 Scan and save the S-scan for the 50-mm focal distance.

A5.2.7 Using the computer display coordinate cursors assess and record the depths, off-sets from the centerline and angles to the side drilled holes in a tabular form. For the side drilled holes at 50-mm radius use the results of the focal laws configured for 50-mm focus and for the holes at 25-mm radius use the focal laws configured for 25 mm.

A5.2.8 Compare the values assessed using the software to the physical positions of the holes in the block. Sound path distances indicated on the computer display should indicate hole positions within ±0.5 mm. Depth and off-set positions of holes should be within ±0.5 mm and all angles to the holes should be within ±1.0°.

A6. ASSESSMENT OF PHASED-ARRAY WEDGE ATTENUATION AND DELAY COMPENSATIONS

A6.1 Introduction

A6.1.1 When an electronic or sectorial scan is used the variations between the electronics of each pulser and receiver and variations between probe elements may result in small gain variations from one focal law to the next. Also, the efficiency of generation varies with angle, and declines away from the "natural" angle of the wedge. When a delay line or refracting wedge is used, variations in path distances within the wedge will result in some focal laws requiring more or less amplifier gain. A method of compensating for gain variations so as to "normalize" the set of focal laws in an electronic or S-scan is required.

A6.1.2 When a phased array probe is used on a delay line or refracting wedge, calculations for beam steering and projection displays rely on the Fermat principle. This requires that the operator identify the position in space of the probe elements. This ensures that the path lengths to the wedge-steel interface are accurately known. It is necessary to verify that the coordinates used by the operator provide correct depth calculations. This ensures that the display software correctly positions indications detected.

A6.1.3 Compensation for attenuation variations and delay times may be made one focal law at a time or software can be configured to make the compensations dynamically.

A6.2 Wedge-attenuation Compensation

A6.2.1 This guide applies to assessments of wedge-attenuation compensations for E-scan or electronic raster scans where 1D linear array probes are used.

A6.2.2 Configure the phased-array system for the focal laws to be used in the electronic raster scan application.

A6.2.3 Acoustically couple the phased array probe to the block with a side drilled hole at a known depth. The 1.5-mm diameter SDH in the IIW block is a convenient target for this purpose.

A6.2.4 Select the A-scan display for the first focal law configured and move the probe forward and backward to locate the maximum amplitude signal from the SDH.

A6.2.5 Adjust the response from the SDH to 80 % full screen height (FSH) and save the parameters in the focal law file.

A6.2.6 Repeat the process of maximizing the signal from the SDH and setting it to 80 % FSH for each focal law and saving the set-up file after each focal law is completed.

A6.2.7 Alternatively, this process may be computerized so that a dynamic assessment of sensitivity adjustment is calculated by the computer. A dynamic assessment would simply require the operator to move the probe back and forth over the SDH ensuring that all the focal laws used have the SDH target move through the beam. Wedge attenuation corrections would then be calculated by the phased-array system to ensure that the amplitude of the SDH detected by each focal law would be adjusted to the same amplitude.

A6.2.8 Assessment of wedge-attenuation compensation requires a constant steel path to ensure that only the effect wedge variations are assessed. For S-scans where 1D linear array probes are used, a single SDH results in a changing steel path for each angle making it unsuitable for this task. A recommended target is a radius similar to that of the 100-mm radius of the IIW block. For S-scans steps A6.2.2 to A6.2.6 are used replacing the SDH with a suitable radius. Use of the radius for S-scan configurations also provides correction for echo-transmittance effects intrinsic in angle variation.

NOTE A6.1—If appropriate compensation cannot be achieved, for example, if the angular range is so large that the signal amplitude cannot effectively be compensated, then the range must be reduced until it is possible to compensate.

A6.2.9 Probe motion for the various wedge and scan-type configurations are illustrated in Fig. A6.1.

A6.3 Wedge-delay Compensation

A6.3.1 When an angled refracting wedge is used for E-scans or S-scans, or when a fixed thickness delay line is used for S-scans, the sound path in the wedge material varies from one focal law to the next. Compensation for this delay time difference is required so as to ensure that indications detected are correctly positioned in the projection scan displays, that is, depth and angle within the test piece are correctly plotted.

A6.3.2 Configure the phased-array system for the focal laws to be used in the S-scan or electronic raster scan application.

A6.3.3 Acoustically couple the phased array probe to a block with known radius of curvature. The 50-mm or 100-mm radius of the IIW block is a convenient target for this purpose.

A6.3.4 Select the A-scan display for the first focal law configured and move the probe forward and backward to locate the maximum amplitude signal from the radius selected.

A6.3.5 Adjust the delay settings to indicate the sound path in the metal to correctly indicate the radius used and save the focal law parameters.

A6.3.6 Repeat the maximization of the radius response for each focal law in the scan set and save the parameter setting after each delay has been adjusted.

A6.3.7 Alternatively, this process may be computerized so that a dynamic assessment of delay adjustment is calculated by the computer. A dynamic assessment would simply require that the operator move the probe back and forth over the center of the radius assuring that all the focal laws used have the center of beam ray peak on the radius appropriate for their angle.

A6.3.8 Small angle compression wave focal laws may require a custom block to carry out this compensation.

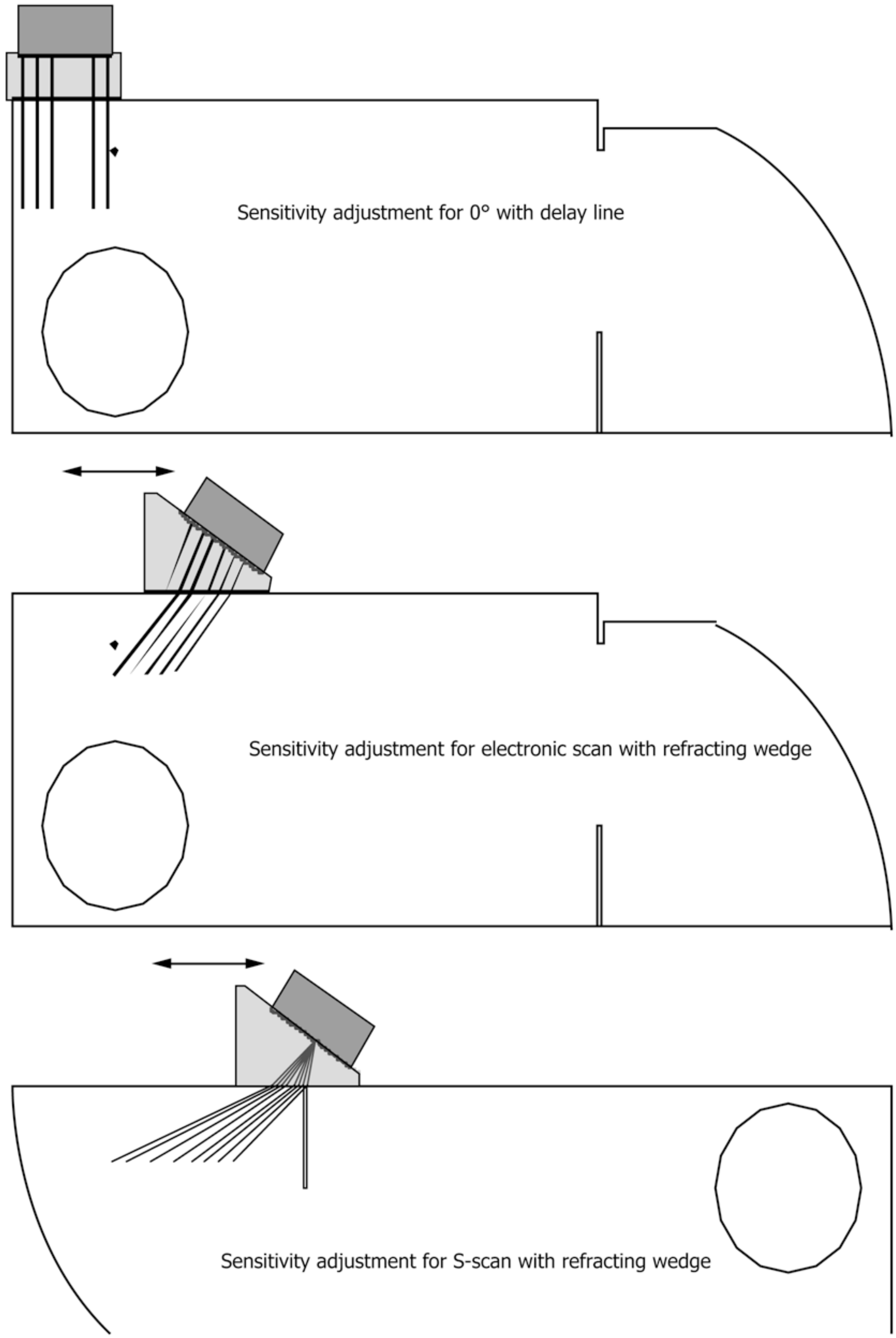


FIG. A6.1 Scan Motion Maximizing Response from SDH to Compensate for Wedge Attenuation

A6.3.9 Probe motion for the various wedge and scan type configurations are illustrated in Fig. A6.2.

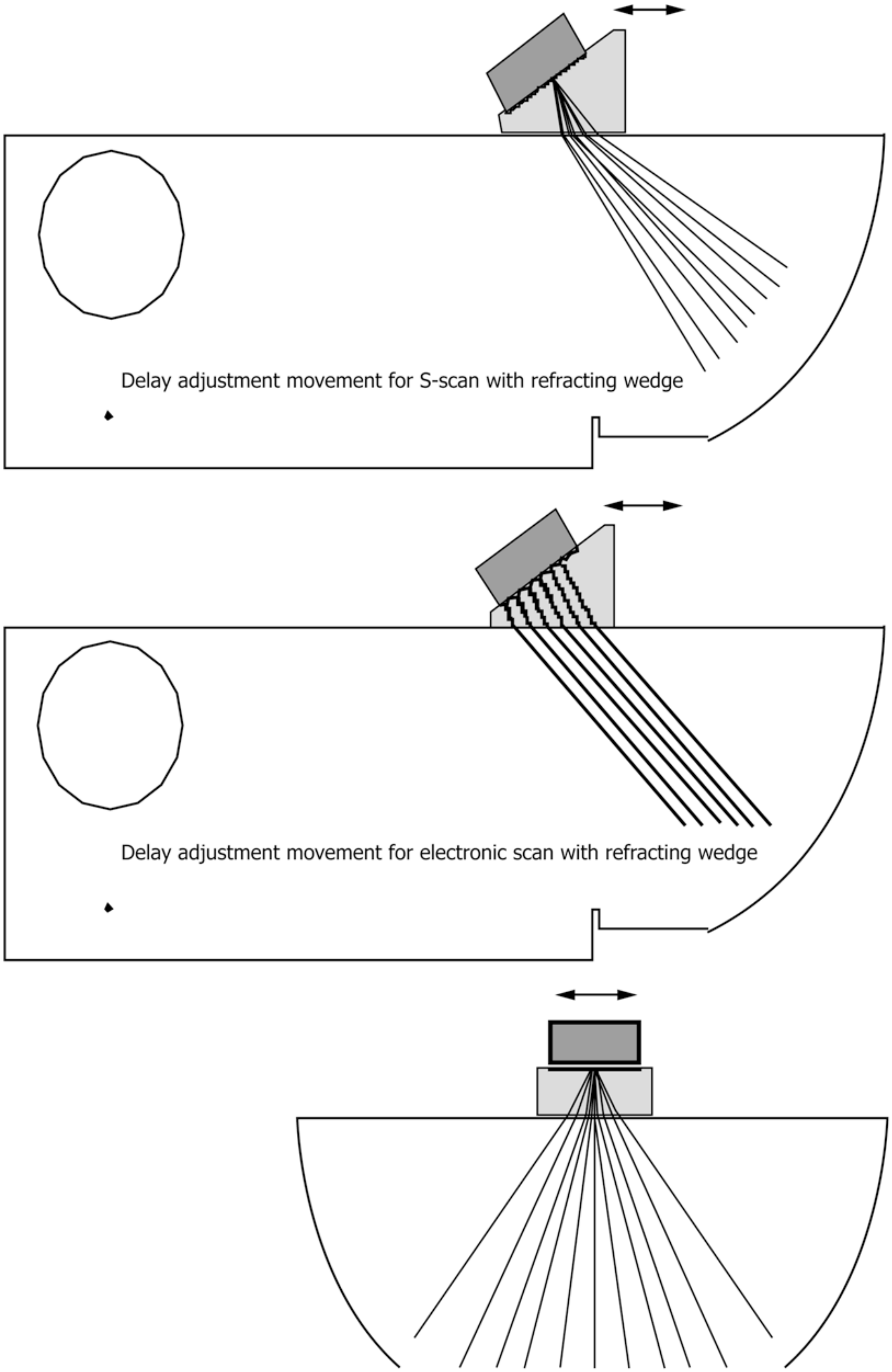


FIG. A6.2 Delay Adjustment Scans Using Curved Surfaces

A7. ASSESSMENT OF PHASED-ARRAY INSTRUMENT LINEARITIES

A7.1 Introduction

A7.1.1 The individual pulser and receiver components of phased-array ultrasonic instruments operate essentially the same as any single channel ultrasonic instrument. Conformance to linearity requirements as described in E317 may be carried out. However, due to the digital-control nature of all phased-array instruments and the fact that multiple pulsers and receivers are used, it is required that phased array instruments be assessed for linearity differently than traditional single-channel units.

A7.2 Test Set-Up

A7.2.1 The phased array instrument is configured to display an A-scan presentation.

A7.2.2 Adjust the time-base of the A-scan to a suitable range to display the pulse-echo signals selected for the linearity verifications. A linearity block similar to that described in E317 is selected to provide signals to assess linearity aspects of the instrument. Such a block is shown in Fig. A7.1 with a single element probe mounted on it.

A7.2.3 Pulser parameters are selected for the frequency and bandpass filter to optimize the response from the pulse-echo (single element) probe used for the linearity verifications.

A7.2.4 The receiver gain is set to display non-saturating signals of interest for display height and amplitude control linearity assessments.

A7.3 Display Height Linearity

A7.3.1 With the phased array instrument connected to a probe (shear or longitudinal) and coupled to any block that will produce two signals as shown in Fig. A7.2 adjust the probe such that the amplitude of the two signals are at 80 % and 40 % of the display screen height. If the phased-array instrument has provision to address a single element probe in pulse-echo mode then the two flat bottom holes with adjustable acoustic impedance inserts in the custom linearity block shown in Fig. A7.1 provides such signals.

A7.3.2 Increase the gain using the receiver gain adjustment to obtain 100 % of full screen height of the larger response. The height of the lower response is recorded at this gain setting as a percentage of full screen height.

NOTE A7.1—For 8-bit digitization systems this value should be 99 %, as 100 % would provide a saturation signal.

A7.3.3 The height of the higher response is reduced in 10 % steps to 10 % of full screen height and the height of the second response is recorded for each step.

A7.3.4 Return the larger signal to 80 % to ensure that the smaller signal has not drifted from its original 40 % level due to coupling variation. Repeat the test if variation of the second signal is greater than 41 % or less than 39 % FSH.

A7.3.5 For an acceptable tolerance, the responses from the two reflectors should bear a 2 to 1 relationship to within ±3 % of full screen height throughout the range 10 % to 100 % (99 % if 100 % is saturation) of full screen height.

A7.3.6 The results are recorded on an instrument linearity form.

A7.4 Amplitude Control Linearity

A7.4.1 A16/64 phased-array instrument has 16 pulsers and receivers that are used to address up to 64 elements. Each of the pulser-receiver components is checked to determine the linearity of the instrument amplification capabilities.

A7.4.2 Select a flat (normal incidence) linear array phased-array probe having at least as many elements as the phased-array ultrasonic instrument has pulsers.

A7.4.3 Using this probe, configure the phased-array ultrasonic instrument to have an electronic raster scan. Each focal

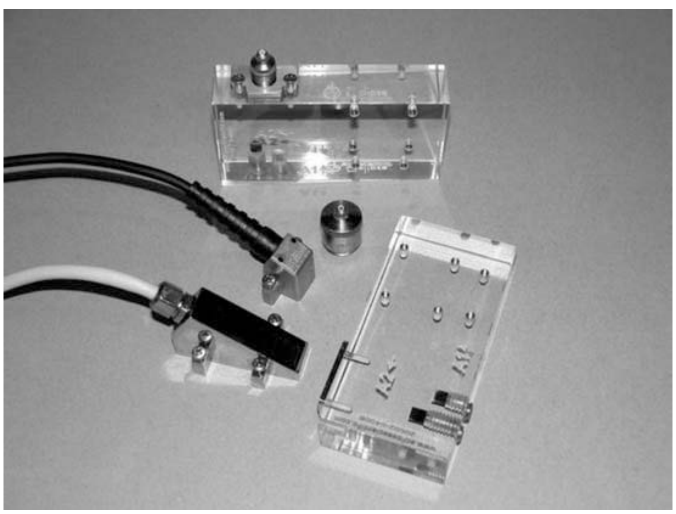


FIG. A7.1 Custom Linearity Blocks for Phased-Array Instrument and Probe Assessments

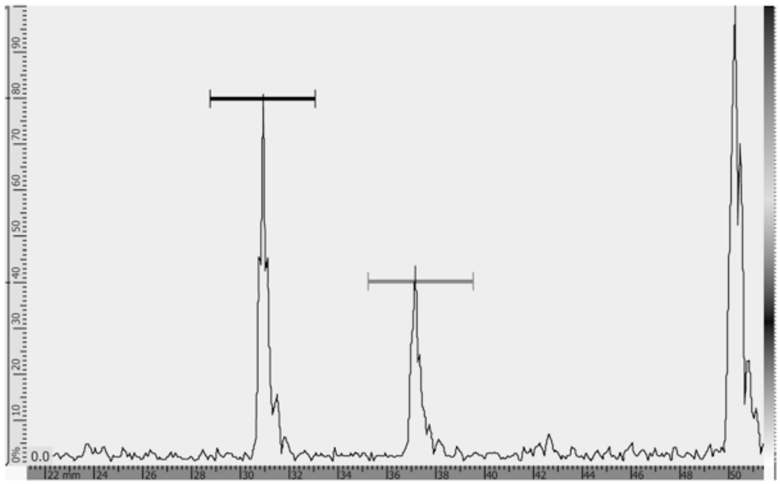


FIG. A7.2 Display Height Linearity

law will consist of one element and the scan will start at element number 1 and end at the element number that corresponds to the number of pulsers in the phased-array instrument.

A7.4.4 Couple the probe to a suitable surface to obtain a pulse-echo response from each focal law. The backwall echo from the 25-mm thickness of the IIW block or the backwall from the 20-mm thickness of the custom linearity block illustrated in Fig. A7.1 provides a suitable target option. Alternatively, immersion testing can be used.

A7.4.5 Select Channel 1 of the pulser-receivers of the phased-array instrument. Using the A-scan display, monitor the response from the selected target. Adjust the gain to bring the signal to 40 % screen height. This is illustrated in Fig. A7.3.

A7.4.6 Add gain to the receiver in the increments of 1 dB, then 2 dB, then 4 dB and then 6 dB. Remove the gain added after each increment to ensure that the signal has returned to 40 % display height. Record the actual height of the signal as a percentage of the display height.

A7.4.7 Adjust the signal to 100 % display height, remove 6-dB gain and record the actual height of the signal as a percentage of the display height.

A7.4.8 Signal amplitudes should fall within a range of ±3 % of the display height required in the allowed height range of Table A7.1.

A7.4.9 Repeat the sequence from A7.4.5 to A7.4.7 for all other pulser-receiver channels.

A7.4.10 For instruments having 10- or 12-bit amplitude digitization and configured to read amplitudes in a gated region to amplitudes greater than can be seen on the display, a larger range of check points can be used. For these instruments the gated output instead of the A-scan display would be verified for linearity.

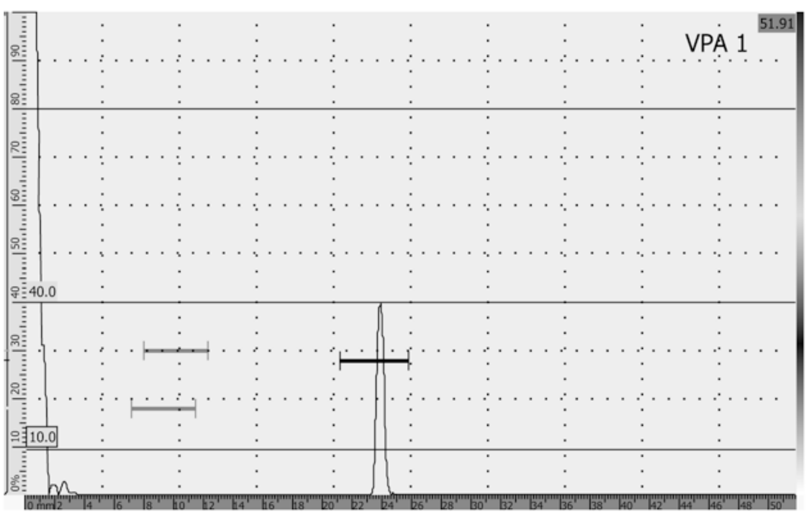


FIG. A7.3 A-Scan Display of Backwall Echo on Channel 1 of a Phased-Array Instrument

TABLE A7.1 LINEARITY VERIFICATION REPORT FORM

Location:			Date:		
Operator:			Signature:		
Instrument:			Couplant:		
Pulser Voltage (V):		Pulse Duration (ns):	Receiver (band):		Receiver smoothing:
Digitization Frequency (MHz):			Averaging:		
Display Height Linearity			Amplitude Control Linearity		
Large (%)	Small Allowed Range	Small Actual (%)	Ind. Height	dB	Allowed Range
100	47-53		40	+1	42-47
90	42-48		40	+2	48-52
80	40	40	40	+4	60-66
70	32-38		40	+6	77-83
60	27-33		40	–6	47-53
50	22-28				
40	17-23				
30	12-18				
20	7-13				
10	2-8				

Amplitude Control Linearity Channel Results: (Note any channels that do not fall in the allowed range)

Channel (Add more if required for 32 or 64 pulser-receiver units)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Time-Base Linearity (for 25-mm IIW blocks)										
Multiple	1	2	3	4	5	6	7	8	9	10
Thickness	25	50	75	100	125	150	175	200	225	250
Measured Interval										
Allowed deviation ±0.5 mm(Yes/No)										

NOTE A7.2—an example of amplitudes greater than 100 % display height is seen in Fig. A7.4 where gate A % indicates a 200 % signal and gate B % indicates 176 %.

A7.5 Time-Base Linearity (Horizontal Linearity)

A7.5.1 Configure the phased array instrument to display an A-scan presentation.

A7.5.2 Select any compression wave probe and configure the phased-array instrument to display a range suitable to obtain at least ten multiple back reflections from a block of a known thickness. The 25-mm wall thickness of the IIW block is a convenient option for this test.

A7.5.3 Set the phased-array instrument analog-to-digital conversion rate to at least 80 MHz.

A7.5.4 With the probe coupled to the block and the A-scan displaying 10 clearly defined multiples as illustrated in Fig. A7.4, the display software is used to assess the interval between adjacent backwall signals.

A7.5.5 Acoustic velocity of the test block, determined using the methods described in E494, is entered into the display software and the display configured to read out in distance (thickness).

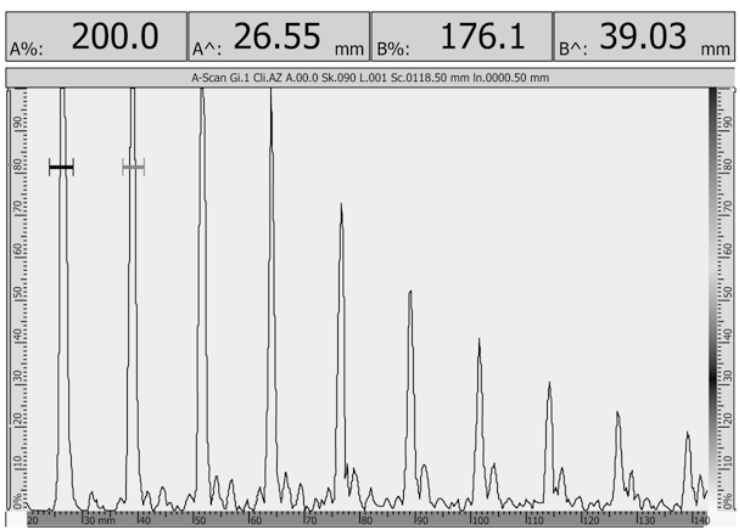


FIG. A7.4 Horizontal Linearity A-Scan

A7.5.6 Using the reference and measurement cursors determine the interval between each multiple and record the interval of the first 10 multiples.

A7.5.7 Acceptable linearity may be established by an error tolerance based on the analog-to-digital conversion rate converted to a distance equivalent. For example, at 100 MHz each sample of the timebase is 10 ns. For steel at 5900 m/s each sample along the timebase (10 ns) in pulse-echo mode represents 30 µm. A tolerance of ±3 timing samples should be achievable by most analog-to-digital systems. Some allowance should be made for velocity determination error (~1 %). Typically the errors on the multiples should not exceed ±0.5 mm for a steel plate.

A7.5.8 A sample recording table for the linearity checks is indicated in Table A7.1.

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STANDARD PRACTICE FOR CONTACT ULTRASONIC TESTING OF WELDS USING PHASED ARRAYS

SE-2700

(Identical with ASTM Specification E2700-14.)

Standard Practice for
Contact Ultrasonic Testing of Welds Using Phased Arrays

1. Scope

1.1 This practice describes ultrasonic techniques for inspecting welds using phased array ultrasonic methods (see Note 1).

1.2 This practice uses angle beams, either in S-scan or E-scan modes, primarily for butt welds and Tee welds. Alternative welding techniques, such as solid state bonding (for example, friction stir welding) and fusion welding (for example, electron beam welding) can be inspected using this practice provided adequate coverage and techniques are documented and approved. Practices for specific geometries such as spot welds are not included. The practice is intended to be used on thicknesses of 9 to 200 mm (0.375 to 8 in.). Greater and lesser thicknesses may be tested using this standard practice if the technique can be demonstrated to provide adequate detection on mockups of the same wall thickness and geometry.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.*

NOTE 1—This practice is based on experience with ferrous and aluminum alloys. Other metallic materials can be examined using this practice provided reference standards can be developed that demonstrate that the particular material and weld can be successfully penetrated by an ultrasonic beam.

NOTE 2—For additional pertinent information, see Practices E2491, E317, and E587.

2. Referenced Documents

2.1 *ASTM Standards:*

E164 Practice for Contact Ultrasonic Testing of Weldments

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E543 Specification for Agencies Performing Nondestructive Testing

E587 Practice for Ultrasonic Angle-Beam Contact Testing

E1316 Terminology for Nondestructive Examinations

E2192 Guide for Planar Flaw Height Sizing by Ultrasonics

E2491 Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems

2.2 *ASME Standard:*

ASME B and PV Code Section V, Article 4

2.3 *ISO Standards:*

ISO 2400 Reference Block for the Calibration of Equipment for Ultrasonic Examination

ISO 9712 Nondestructive Testing—Qualification and Certification of NDT Personnel

2.4 *ASNT Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of NDT Personnel

2.5 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E1316.

4. Summary of Practice

4.1 Phased arrays are used for weld inspections for numerous applications. Industry specific requirements have been developed to control the use of this technology for those applications. A general standard practice document is required to define the requirements for wider use of the technology. Several manufacturers have developed portable, user-friendly instruments. Codes and code cases have been developed, or are being developed, to cover phased array weld inspection requirements by organizations such as ASME. Practice E2491 covers setting up of phased arrays for weld inspections. Training programs for phased arrays have been set up worldwide. This practice provides procedural guidance for both manual and mechanized scanning of welds using phased array systems.

5. Significance and Use

5.1 Industrial phased arrays differ from conventional monocrystal ultrasonic transducers since they permit the electronic control of ultrasound beams. The arrays consist of a series of individual transducer elements, each separately wired, time-delayed and electrically isolated; the arrays are typically pulsed in groups to permit "phasing," or constructive-destructive interference.

5.2 Though primarily a method of generating and receiving ultrasound, phased arrays are also a method of scanning and imaging. While some scan patterns emulate manual technology, other scans (for example, S-scans) are unique to phased arrays. With their distinct features and capabilities, phased arrays require special set-ups and standardization, as addressed by this practice. Commercial software permits the operator to easily make set ups without detailed knowledge of the phasing requirements.

5.3 Phased arrays can be used in different ways: manual or encoded linear scanning; and different displays or combinations of displays. In manual scanning, the dominant display will be an S-scan with associated A-scans. S-scans have the advantage over E-scans that all the specified inspection angles can be covered at the same time.

5.4 The main advantages of using phased arrays for ultrasonic weld examinations are:

5.4.1 Faster scanning due to multiple angles on display at the same time,

5.4.2 Better imaging from the true depth S-scan,

5.4.3 Data storage, for example, selected reflectors, for auditing, and archiving.

5.4.4 Rapid and reproducible set-ups with electronic instruments.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, ISO 9712, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.2.1 In addition, there should also be training or knowledge and experience related to phased array equipment and techniques. Personnel performing examinations to this standard should list the qualifying credentials in the examination report.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be used shall be as specified in the contractual agreement. Practice E2491 recommends methods of assessing performance characteristics of phased array probes and systems.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with 9.1 unless otherwise specified.

6.6 *Timing of Examination*—The timing of examination shall be determined by the contracting parties and in accordance with the stage of manufacture or in-service conditions.

6.7 *Extent of Examination*—The extent of examination shall be suitable to examine the volume of the weld plus the heat affected zone unless otherwise specified.

6.8 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with 13.1, unless otherwise specified. Since acceptance criteria are not specified in this standard, they shall be specified in the contractual agreement.

6.9 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7. Equipment

7.1 *Phased Array Instruments:*

7.1.1 The ultrasonic phased array instrument shall be a pulse echo type and shall be equipped with a standardized dB gain or attenuation control stepped in increments of 1 dB minimum, containing multiple independent pulser/receiver channels. The system shall be capable of generating and displaying both B-scan and S-scan images, which can be stored and recalled for subsequent review.

7.1.2 The phased array system shall have on-board focal law generation software that permits direct modification to ultrasonic beam characteristics. Specific delay calculations may be performed by the system itself or imported from external calculations.

7.1.3 The phased array system shall have a means of data storage for archiving scan data. An external storage device, flash card or USB memory stick can be used for data storage. A remote portable PC connected to the instrument may also be used for this purpose. If instruments do not inherently store A-scan data, such as some manual instruments, the final image only may be recorded.

7.1.4 The phased array system shall be standardized for amplitude and height linearity in accordance with Practice E2491 annually, as a minimum.

7.1.5 The instrument shall be capable of pulsing and receiving at nominal frequencies of 1 MHz to 10 MHz. For special applications, frequencies up to 20 MHz can be used, but may require special instrumentation with appropriate digitization, and special approval.

7.1.6 The instrument shall be capable of digitization of A-scans at a minimum of five times the nominal frequency of the probe used. Amplitude shall be digitized at a resolution of at least 8-bit (that is, 256 levels).

7.1.7 The instrument shall be capable of equalizing the amplitude response from a target at a fixed soundpath for each angle used in the technique (angle corrected gain (ACG) thereby providing compensation for wedge attenuation variation and echo-transmittance).

7.1.8 The instrument shall also be equipped with facilities to equalize amplitudes of signals across the time-base (time-corrected gain).

7.2 *Phased Array Probes:*

7.2.1 The application requirements will dictate the design of the phased array probe used. Phased array probes may be used with a removable or integral wedge, delay-line, or in an immersion or localized bubbler system mode. In some cases a phased array probe may be used without a refracting wedge or delay-line (that is, just a hard wear-face surface).

7.2.2 Phased array probes used for weld examination may be of 1D, 1.5D or 2D design. Only 1D arrays or dual arrays configured with side-by-side transmitter-receiver arrays (as in Transmit-Receive Longitudinal wave probes) shall be used with manual scanning techniques. For 2D arrays, which use electronic oscillation, calibration should be performed at all skewed angles.

7.2.3 The number of elements in the phased array probe and the element dimensions and pitch shall be selected based on the application requirements and the manufacturer's recommended limitations.

7.2.4 The probe selected shall not have more elements than the number of elements addressable by the pulser-receivers available in the phased array instrument being used.

7.2.5 When refracting wedges are used to assist beam steering, the natural incident angle of the wedge shall be selected such that the angular sweep range of the examination technique used does not exceed the manufacturer's recommended limits for the probe and mode (compression or transverse) used.

7.2.6 Refracting wedges used on curved surfaces shall require contouring to match the surface curvature if the curvature causes a gap between the wedge and examination surface exceeding 0.5 mm (0.020 in.) at any point.

8. Standardization

8.1 *Range:*

8.1.1 The instrument display shall be adjusted using the A-scans for each focal law used to provide an accurate indication of sound travel in the test material. Range standardization shall include correction for wedge travel time so that the zero-depth position in the test piece is accurately indicated for each focal law.

8.1.2 Time base linearity and accuracy shall be verified in accordance with the guidelines in Practice E2491, or Practice E317, or both.

8.1.3 Volume-corrected B-scan or S-scan displays shall indicate the true depth to known targets to within 5 % of the physical depth or 3 mm, whichever is less.

8.1.4 Range standardization shall be established using the radius surfaces in reference blocks such as the IIW Block and these blocks shall be made of the same material or acoustically similar material as the test piece.

8.2 *Sensitivity:*

8.2.1 Reference standards for sensitivity-amplitude standardization should be designed so that sensitivity does not vary with beam angle when angle beam testing is used. Sensitivity amplitude reference standards that accomplish this are side-drilled holes parallel to the major surfaces of the plate and perpendicular to the sound path, flat-bottomed holes drilled at the testing angle, and equal-radius reflectors. Surface notches may be used under some circumstances but are not generally recommended.

8.2.2 Standardization shall include the complete ultrasonic phased array system and shall be performed prior to use of the system in the thickness range under examination.

8.2.3 Standardization on reference block(s) shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the component from which the examination will be performed.

8.2.4 The same couplant to be used during the examination shall be used for standardization.

8.2.5 The same contact wedges or immersion/bubbler systems used during the examination shall be used for standardization.

8.2.6 The same focal law(s) used in standardization shall be used for examination.

8.2.7 Any control which affects instrument amplitude response (for example, pulse-duration, filters, averaging, etc.) shall be in the same position for standardization and examination.

8.2.8 Any control which affects instrument linearity (for example, clipping, reject, suppression) shall not be used.

8.2.9 A baseline assessment of element activity shall be made in accordance with Annex A3 of Practice E2491.

9. Coupling Conditions

9.1 *Preparation:*

9.1.1 Where accessible, prepare the surface of the deposited weld metal so that it merges into the surfaces of the adjacent base materials; however, the weld may be examined in the as-welded condition, provided the surface condition does not interfere with valid interpretation of indications.

9.1.2 Clean the scanning surfaces on the base material of weld spatter, scale, dirt, rust, and any extreme roughness on each side of the weld for a distance equal to several times the thickness of the production material, this distance to be governed by the size of the search unit and refracted angle of the sound beam. Where scanning is to be performed along the top or across this weld, the weld reinforcement may be ground to provide a flat scanning surface. It is important to produce a surface that is as flat as possible. Generally, the surfaces do not require polishing; light sanding with a disk or belt sander will usually provide a satisfactory surface for examination.

9.1.3 The area of the base material through which the sound will travel in the angle-beam examination should be completely scanned with a straight-beam search unit to detect reflectors that might affect the interpretation of angle-beam results by obstructing the sound beam. Consideration must be given to these reflectors during interpretation of weld examination results, but their detection is not necessarily a basis for rejection of the base material.

9.2 *Couplant:*

9.2.1 A couplant, usually a liquid or semi-liquid, is required between the face of the search unit and the surface to permit transmission of the acoustic energy from the search unit to the material under examination. The couplant should wet the surfaces of the search unit and the test piece, and eliminate any air space between the two. Typical couplants include water, oil, grease, glycerin, and cellulose gum. The couplant used should not be injurious to the material to be examined, should form a thin film, and, with the exception of water, should be used sparingly. When glycerin is used, a small amount of wetting agent is often added, to improve the coupling properties. When water is used, it should be clean and de-aerated if possible. Inhibitors or wetting agents, or both, may be used.

9.2.2 The coupling medium should be selected so that its viscosity is appropriate for the surface finish of the material to be examined.

9.3 For contact examination, the temperature differential between the reference block and examination surface shall be within 15°C (25°F).

10. Distance-Amplitude Correction

10.1 Reference standards for sensitivity-amplitude standardization should be constructed of materials with similar surface finish, nominal thickness and metallurgically similar in terms of alloy and thermal treatment to the weldment.

10.2 Alternative methods of distance-amplitude of correction of sensitivity may be used provided the results are as reliable as those obtained by the acceptable method. In addition, the alternative method and its equipment shall meet all the performance requirements of this standard.

10.3 *Reference Reflectors:*

10.3.1 Straight-Beam Standardization—Correction for straight beam examination may be determined by means of a side drilled hole reflector at ¼ and ¾ of the thickness. For thickness less than 50 mm (2 in.), the ¼-thickness reflector may not be resolved. If this is the case, drill another hole at ½ thickness and use the ½ and ¾-thickness reflectors for correction.

10.3.2 *Angle-Beam Standardization*—Correction for angle-beam examination may be determined by means of side-drilled hole reflectors at ¼ and ¾ of the thickness. The ½-thickness depth to a side-drilled hole may be added to the standardization or used alone at thicknesses less than 25 mm (1 in.). For certain combinations of thin wall and small diameter pipe side drilled holes may not be practical and surface notches may be used with agreement between contracting parties.

10.3.3 The size of the side-drilled hole used for setting sensitivity shall be agreed upon by the contracting parties. Other targets may be substituted for side-drilled holes if agreed upon by the contracting parties.

10.4 *Acceptable Technique:*

10.4.1 *Time-Corrected Gain*—Assessment of phased array examinations uses color-coded B-scans or S-scans as the initial evaluation method. Therefore, it is necessary that the display used provide a uniform color code related to amplitude at all sound path distances. This method can be used only if the instrument is provided with electronic distance amplitude compensation circuitry (TCG). Use is made of all reflectors in the standardization range. The test equipment, probe(s), focal law(s), couplant, etc., to be used in the ultrasonic examination shall be used for this attenuation adjustment.

10.4.2 With the instrument display in time or sound path (not true depth) locate the focal law that provides the maximum response from the reference targets. Set the signal from the reference reflector that gives the highest response, to a screen height of between 40 % to 80 % full screen height (FSH). This target may be considered the primary reference reflector.

10.4.3 Using the same focal law, maximize each of the other reference reflectors at other distances over the range to be used for examination, adjusting the electronic distance amplitude correction controls to equalize the screen height from these reference reflectors to the primary reflector. Apply the correction to all focal laws used for the examination.

10.4.4 Other methods of accomplishing the equalization of amplitude for all focal laws used from equal-size reflectors over the examination distance range may be used. The method for the system used is best described for each instrument in the operating manual for that instrument.

10.4.5 An example of sensitivity standardization for weld examination using side-drilled holes is shown in Fig. 1. Note the amplitude responses from the side drilled holes is the same for each hole even though the angle used to detect the hole and the sound path to the hole is different in each instance. The modeled coverage in the upper portion of Fig. 1 illustrates the beams as if they were projected instead of reflected off the opposite wall. The weld profile overlay allows visualization sound path to the side drilled holes.

10.5 Periodic checks of the sensitivity shall be made at a frequency agreed upon by the contracting parties. If the equipment has changed by more than the agreed upon tolerances, it shall be re-standardized. If the source of sensitivity change is a result of change in the number of active elements compared to the baseline assessment it may require probe replacement.

11. Examination Procedures

11.1 Phased array examination procedures are nominally identical to conventional ultrasonic procedures in coverage, angles etc. Examination procedures recommended for common weld configurations are detailed in Practice E164. Variations in

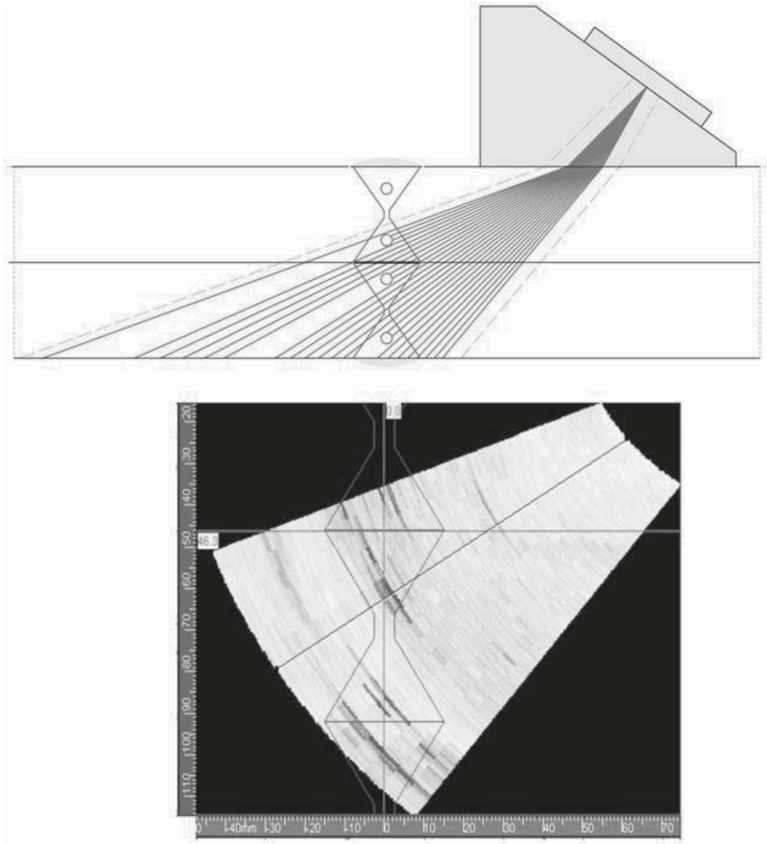


FIG. 1 Modeled S-scan and S-scan Display of Side-Drilled Holes Corrected to 80 % Screen Height Using TCG

specifics of the procedures for phased array methods are required depending on whether manual or encoded scanning is used.

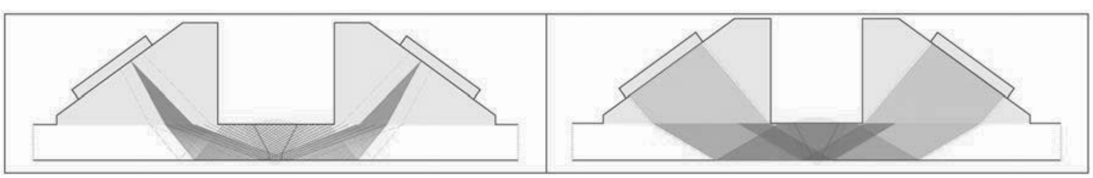
11.2 Phased array scanning procedures for welds shall be established using scan plans that indicate the required stand-off positions for the probe to ensure volume coverage required and appropriate beam angles. Volume coverage required may include the full volume of weld plus a specified region either side (such as the heat affected zone). Welds shall be inspected from both sides, where possible.

11.3 In addition, if cross-cracking (transverse cracking) is suspected, a supplementary technique shall be used that directs the beam parallel or essentially parallel to the weld centerline. The technique used will depend on whether or not the weld reinforcement has been ground flush or not.

11.4 Typically scanning is carried out from the surfaces where the plate has been machined with the weld bevel. Alternative scanning techniques shall be used for different weld profiles. Sample illustrations are shown in Figs. 2-7. Not all possible configurations are illustrated; illustrations are examples only. Volume coverage afforded by multiple stand-off positions of probes are illustrated for encoded linear scans. This can be replaced with raster scanning where the stand-offs are continuously varied to the limits required using manual movement of the probes.

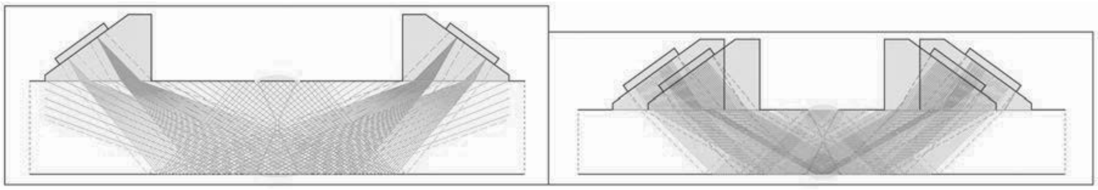
11.5 Scanning may be by manual probe motion or automated or semi-automated motion.

11.6 For manual scanning the primary scan pattern is a raster motion with the beam directed essentially perpendicular to the weld axis. The distance forward and backward that the



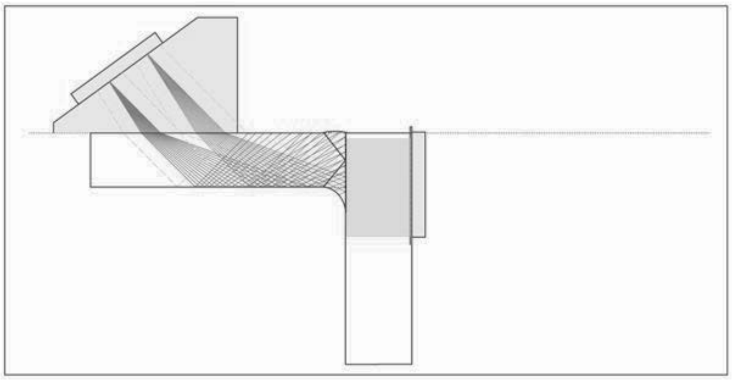
NOTE 1—Butt welds should be examined from both sides of the weld and preferably from the bevel opening side (when access permits). For thin wall sections, a single probe stand-off may be possible for linear scanning if the probe parameters are adequate for full volume coverage.

FIG. 2 Thin Butt Weld (S and E Scans)



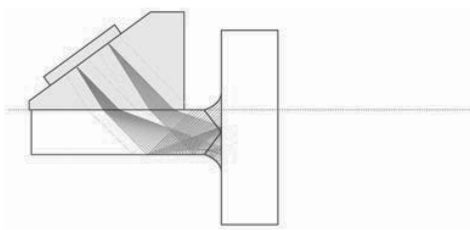
NOTE 1—Butt welds should be examined from both sides of the weld and preferably from the bevel opening side (when access permits). For thick wall sections, multiple probe stand-offs or multiple focal law stand-offs will be required for linear scanning to ensure full volume coverage.

FIG. 3 Thick Butt Welds (S and E Scans)



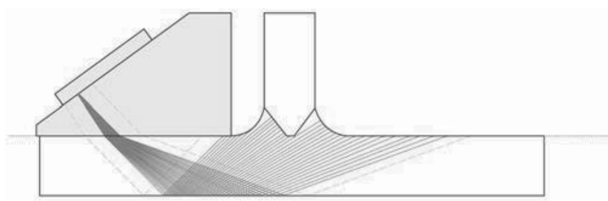
NOTE 1—Corner welds are to be addressed using a combination of angle beams and straight beams. The preferred probe placement for the angle beam is on the surface where the weld bevel opening occurs. For double Vee welds, angle beam examinations should be carried out from both surfaces when access permits. In most cases, the surface from which the straight beam is used needs no further examination using angle beams.

FIG. 4 Corner Welds (Combined S and E Scans)



NOTE 1—T-weld examinations may be treated similarly to butt welds. For thin sections, it may be possible to use a single stand-off position with either E-scans or S-scans. Examination from both surfaces of the web-plate plate should be used when access permits.

FIG. 5 T-Weld (from Web)

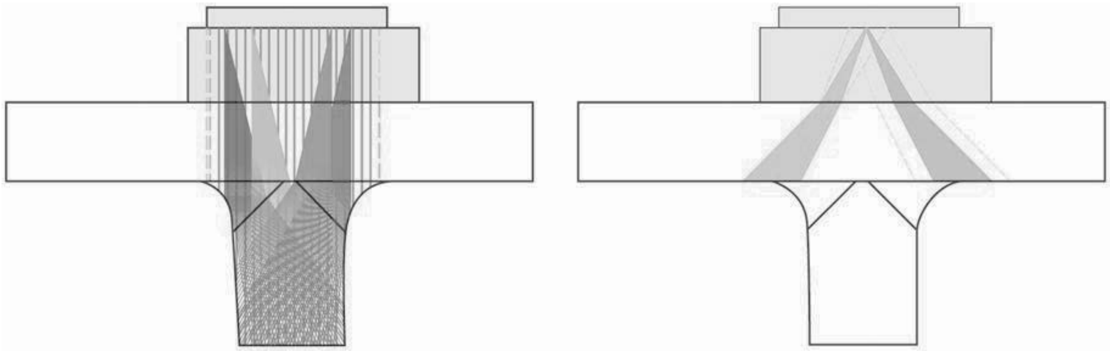


NOTE 1—An alternative to the technique illustrated in Fig. 5 for T-welds is to use refracted shear wave S-scans or E-scans from web-side of flange surface. More than one stand-off position may be required for thicker sections. Examination from both sides of the web plate should be used when access permits. This technique is not generally considered to be as effective as the technique described in Fig. 5.

FIG. 6 Tee Welds (from Flange)

probe is moved is determined by the scan plan to ensure full volume coverage. The lateral movement on each raster step shall not exceed half the element dimension in the lateral direction. Scanning speed (speed at which the probe is manually moved forward and backward) will be limited by the system update capabilities. Generally using more focal laws requires more processing time so update rates of the B-scan or S-scan displays are slower as more focal laws are used.

11.7 For automated or semi-automated scanning the probe will be used with a positional encoder for each axis in which probe motion is required (for most applications a single



NOTE 1—When access permits, the preferred technique for T-weld examinations is from the plate opposite the web. A combination of 0° E-scans, and angled compression and shear modes from each direction provides the best approach for flaw detection along the fusion faces of the weld.

FIG. 7 Tee Welds (from Flange Opposite Web)

encoder is used). The encoder shall be calibrated to provide positional information from a reference start position and shall be accurate to within 1 % of total scan length or 10 mm (0.4 in.), whichever is less. Guide mechanisms such as probe holding frames or magnetic strips are used to ensure that the probe moves at a fixed distance from the weld centerline. Data, in the form of A-scans from each focal law used, shall be collected at increments of not greater than 2 mm (with at least three increments for the length of the smallest required detectable defect, that is, a defect length of 3 mm would require increments of not greater than 1 mm) along the scan axis. Note that this interval should be reduced when length sizing of flaws is critical with respect to the acceptance criteria. If laterally focused beams are used, this can be considered for data collection increments as above.

11.8 For encoded scanning only, multiple probes and multiple focal law groups (for example, two S-scans from the same probe but having difference start elements) may be used simultaneously if the system has the capability. Probe placement will be defined by the details of the scan plan with confirmation of coverage confirmed using notches that may be incorporated into the reference block.

12. Indication Evaluation

12.1 The method of evaluation used, will to some extent, depend on whether manual or encoded scanning was used.

12.2 *Manual Scanning:*

12.2.1 For manual scanning using phased arrays examination personnel shall use a real-time S-scan or B-scan display during scanning to monitor for coupling quality and signals exceeding the evaluation threshold.

12.2.2 Evaluation of indications detected using manual phased array methods shall require the operator to assess all indications exceeding the evaluation threshold when the indication is detected during the scanning process. Some phased-array systems may include options for entering some items into a report format and incorporating S-scan or B-scan images as part of the report.

12.3 *Encoded Scanning:*

12.3.1 Encoded scanning methods rely on assessment of data displays produced from stored A-scans.

12.3.2 Encoded systems may be equipped with real-time displays to display one or more views of data being collected during the scan. This feature will be used only for assessment of data quality as the scan is progressing and may allow for one or more channels to be monitored.

12.3.3 Evaluation of indications detected by encoded phased array scanning shall be made using the digitized waveforms underlying the S-scans or B-scans collected during the data acquisition process.

12.3.4 Encoded scanning data displays for indication evaluation may use a variety of projections other than just the S-scans or B-scans available to manual scanning (for example, top-side-end views).

12.3.5 Welds scanned using encoded techniques may be scanned in sections provided that there is an overlap of data collected and the overlap between scans is identified in the encoded position with respect to the weld reference start position (for example, a 2-m long weld may be scanned in two parts; one from 0 to 1000 mm and the second from 950 to 2000 mm).

12.3.6 The evaluation threshold should be indicated on the S-scan or B-scan display as a well defined color such that indications of note are easily distinguished from the background level.

12.3.7 S-scan or B-scan images presented with angular correction (also referred to as volume corrected) contain signal amplitude and indication depth information projected for the refracted angle of the ultrasonic beam.

12.3.8 Indication locations shall be determined relative to the inspection surface and a coordinate system that uses well defined reference for the relative to the weld.

12.4 *Indication Size Determination:*

12.4.1 Indication length is generally determined by determining the distance between the points along the weld length where the amplitude drops to half the maximum at the extremities of the reflector, or when the amplitude drops to half the minimum evaluation amplitude.

12.4.2 Estimates of indication height can be made using the 6-dB drop as determined from the S-scan or B-scan (see Fig. 8). This method is suitable for large planar flaws with extents greater than the beam. For flaws with dimensions smaller than

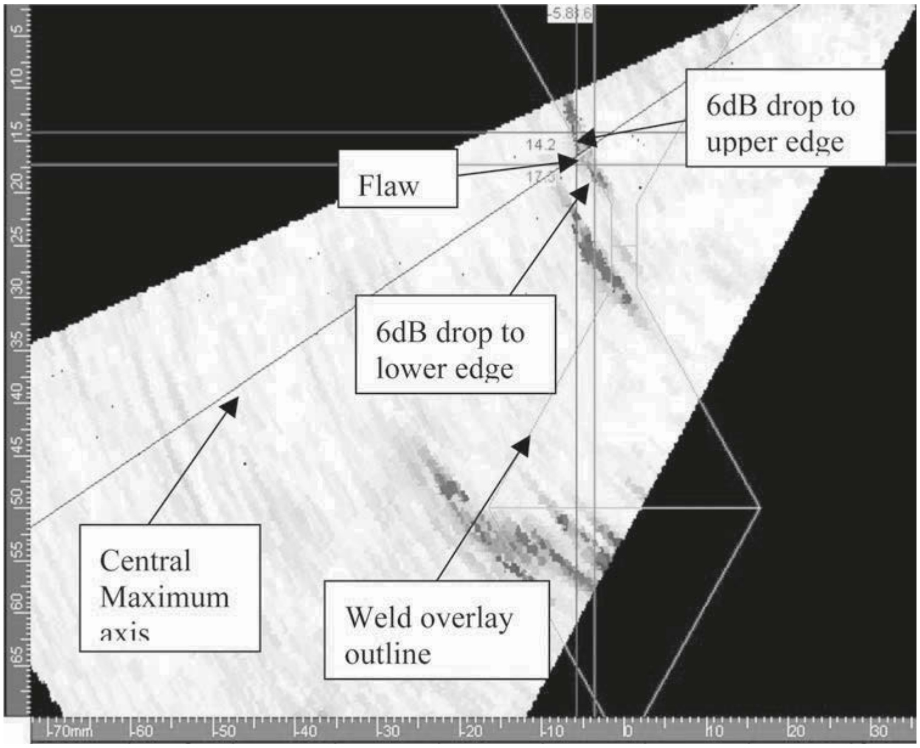


FIG. 8 Flaw Sizing (Vertical) by 6dB Drop

the beam a correction for beam divergence may be used to improve sizing estimates. For adversely oriented indications or indications with irregular surfaces, amplitude sizing techniques may not accurately indicate size or severity of the indications. For improved sizing capabilities techniques described in Guide E2192 may be more suitable and can be adapted to phased array applications.

12.4.3 Evaluation of all relevant indications will be made against the acceptance criteria agreed upon by the contracting parties.

13. Reporting

13.1 The contracting parties should determine the pertinent items to be reported. This may include the following information:

13.2 Weld details including thickness dimensions, material, weld process and bevel shape. Descriptive sketches are usually recommended.

13.2.1 Scan surfaces and surface conditions.

13.2.2 *Equipment:*

13.2.2.1 Phased array ultrasonic instrument details.

13.2.2.2 Phased array probe details including:

(1) Number of elements,

(2) Frequency,

(3) Element pitch dimensions,

(4) Focus (identify plane, depth or sound path as applicable and if applicable),

(5) Wedge (velocity, incident angle, dimensions, reference dimensions to first element).

13.2.3 Virtual aperture use, that is, number of elements and element width,

13.2.4 Element numbers used for focal laws,

13.2.5 Angular range of S-scan,

13.2.6 Documentation on recommended wedge angular range from manufacturer,

13.2.7 Documented calibration, TCG and angle gain compensation,

13.2.8 Encoder(s),

13.2.9 Scanning mechanisms used,

13.2.10 Couplant,

13.2.11 Method of sensitivity standardization and details of correlating indications with flaws,

13.2.12 Scan plan (indicating probe position on test piece, probe movement, angles used and volume coverage,

13.2.13 Mode of transmission (compression, shear, pulse-echo, tandem, through transmission),

13.2.14 Scanning results (flaw details such as length, position, height, amplitude, acceptability with respect to agreed specifications),

13.2.15 Operator name,

13.2.16 Date of examination.

14. Keywords

14.1 nondestructive testing; phased arrays; phased array probe; ultrasonic contact examination; ultrasonic NDT of welds; welds

ARTICLE 24
LIQUID PENETRANT STANDARDS

STANDARD TEST METHOD FOR SULFUR IN PETROLEUM PRODUCTS (GENERAL HIGH PRESSURE DECOMPOSITION DEVICE METHOD)

SD-129

(Identical with ASTM Specification D129-13.)

Standard Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)

1. Scope

1.1 This test method covers the determination of sulfur in petroleum products, including lubricating oils containing additives, additive concentrates, and lubricating greases that cannot be burned completely in a wick lamp. The test method is applicable to any petroleum product sufficiently low in volatility that it can be weighed accurately in an open sample boat and containing at least 0.1 % sulfur.

NOTE 1—This test method is not applicable to samples containing elements that give residues, other than barium sulfate, which are insoluble in dilute hydrochloric acid and would interfere in the precipitation step. These interfering elements include iron, aluminum, calcium, silicon, and lead which are sometimes present in greases, lube oil additives, or additive oils. Other acid insoluble materials that interfere are silica, molybdenum disulfide, asbestos, mica, and so forth. The test method is not applicable to used oils containing wear metals, and lead or silicates from contamination. Samples that are excluded can be analyzed by Test Method D1552.

1.2 This test method is applicable to samples with the sulfur in the range 0.09 to 5.5 mass %.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D1193 Specification for Reagent Water

D1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)

D6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance

E144 Practice for Safe Use of Oxygen Combustion Bombs

3. Summary of Test Method

3.1 The sample is oxidized by combustion in a high pressure decomposition device containing oxygen under pressure. The sulfur, as sulfate in the high pressure decomposition device washings, is determined gravimetrically as barium sulfate.

3.2 (**Warning—**Strict adherence to all of the provisions prescribed hereafter ensures against explosive rupture of the high pressure decomposition device, or a blow-out, provided the high pressure decomposition device is of proper design and construction and in good mechanical condition. It is desirable, however, that the high pressure decomposition device be enclosed in a shield of steel plate at least 13 mm thick, or equivalent protection be provided against unforeseeable contingencies.)

3.3 (**Warning—**Initial testing and periodic examination of the pressure vessel is essential to ensure its fitness for service. This is particularly important if the pressure vessel has been dropped and has any obvious signs of physical damage.)

4. Apparatus and Materials

4.1 *High Pressure Decomposition Device (see Note 2),* having a capacity of not less than 300 mL, so constructed that it will not leak during the test and that quantitative recovery of the liquids from the high pressure decomposition device may be achieved readily. The inner surface of the high pressure decomposition device may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the high pressure decomposition device assembly, such as the head gasket and lead-wire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the sulfur content of the liquid in the high pressure decomposition device.

NOTE 2—Criteria for judging the acceptability of new and used oxygen combustion high pressure decomposition devices are described in Practice E144.

4.2 *Oxygen Charging Equipment*—The valves, gauges, filling tube, and fittings used in the oxygen charging system shall meet industry safety codes and be rated for use at input pressure up to 20 875 kPa and discharge pressure up to 5575 kPa. Separate gauges shall be provided to show the supply pressure and the pressure vessel pressure. The pressure vessel gauge shall not be less than 75 mm in diameter and preferably graduated from 0 kPa to 5575 kPa in 100 kPa subdivisions. Both gauges shall be absolutely oil-free and shall never be tested in a hydraulic system containing oil. The charging equipment shall include either a pressure reducing valve which will limit the discharge pressure to a maximum of 4055 kPa or a relief valve set to discharge at 4055 kPa in case the pressure vessel should accidentally be overcharged. Means shall also be provided for releasing the residual pressure in the filling tube after the pressure valve has been closed.

4.3 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g.

4.4 *Firing Wire,* platinum, No. 26 B & S gage, 0.41 mm (16 thou), 27 SWG, or equivalent. (**Warning—**The switch in the ignition circuit shall be of a type which remains open, except when held in closed position by the operator.)

4.5 *Ignition Circuit,* capable of supplying sufficient current to ignite the cotton wicking or nylon thread without melting the wire. The current shall be drawn from a step-down transformer or from a suitable battery. The current shall not be drawn from the power line, and the voltage shall not exceed 25 V. The switch in the ignition circuit shall be of a type which remains open, except when held in closed position by the operator.

4.6 *Cotton Wicking or Nylon Sewing Thread,* white.

4.7 *Muffle Furnace.*

4.8 *Filter Paper,* "ashless," 0.01 mass % ash maximum.

5. Reagents and Materials

5.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 *Purity of Water*—Unless otherwise indicated, references to water shall mean water as defined by Type II or III of Specification D1193.

5.3 *Barium Chloride Solution* (85 g/L)—Dissolve 100 g of barium chloride dihydrate ($BaCl_2 \cdot 2H_2O$) in distilled water and dilute to 1 L.

5.4 *Bromine Water (saturated)* .

5.5 *Hydrochloric Acid* (sp gr 1.19)—Concentrated hydrochloric acid (HCl).

5.6 *Oxygen,* free of combustible material and sulfur compounds, available at a pressure of 41 kgf/cm^2 (40 atm).

5.7 *Sodium Carbonate Solution* (50 g/L)—Dissolve 135 g of sodium carbonate decahydrate ($Na_2CO_3 \cdot 10H_2O$) or its equivalent weight in distilled water and dilute to 1 L.

5.8 *White Oil, USP, or Liquid Paraffin,* BP, *or equivalent.*

5.9 *Quality Control (QC) Samples,* preferably are portions of one or more liquid petroleum materials that are stable and representative of the samples of interest. These QC samples can be used to check the validity of the testing process as described in Section 10.

6. Procedure

6.1 *Preparation of High Pressure Decomposition Device and Sample*—Cut a piece of firing wire 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Insert between two loops of the coil a wisp of cotton or nylon thread of such length that one end will extend into the sample cup. Place about 5 mL of Na_2CO_3 solution in the high pressure decomposition device (Note 3) and rotate the high pressure decomposition device in such a manner that the interior surface is moistened by the solution. Introduce into the sample cup the quantities of sample and white oil (Note 4 and Note 5) specified in the following table, weighing the sample to the nearest 0.2 mg (when white oil is used, stir the mixture with a short length of quartz rod and allow the rod to remain in the sample cup during the combustion).

NOTE 3—After repeated use of the high pressure decomposition device for sulfur determinations, a film may be noticed on the inner surface. This dullness can be removed by periodic polishing of the high pressure decomposition device. A satisfactory method for doing this is to rotate the high pressure decomposition device in a lathe at about 300 rpm and polish the inside surface with emery polishing papers Grit No. 2⁄0, or equivalent paper, coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before the high pressure decomposition device is used it shall be washed with soap and water to remove oil or paste left from the polishing operation.

6.1.1 (**Warning—**Do not use more than 1.0 g total of sample and white oil or other low sulfur combustible material or more than 0.8 g if the IP 12 high pressure decomposition device is used.)

Sulfur Content percent	Weight of Sample, g	Weight of White Oil, g
5 or under	0.6 to 0.8	0.0
Over 5	0.3 to 0.4	0.3 to 0.4

NOTE 4—Use of sample weights containing over 20 mg of chlorine may cause corrosion of the high pressure decomposition device. To avoid this, it is recommended that for samples containing over 2 % chlorine, the sample weight be based on the chlorine content as given in the following table:

Chlorine Content percent	Weight of Sample, g	Weight of White Oil, g
2 to 5	0.4	0.4
Over 5 to 10	0.2	0.6
Over 10 to 20	0.1	0.7
Over 20 to 50	0.05	0.7

NOTE 5—If the sample is not readily miscible with white oil, some other low sulfur combustible diluent may be substituted. However, the combined weight of sample and nonvolatile diluent shall not exceed 1.0 g or more than 0.8 g if the IP 12 high pressure decomposition device is used.

6.2 *Addition of Oxygen*—Place the sample cup in position and arrange the cotton wisp or nylon thread so that the end dips into the sample. Assemble the high pressure decomposition device and tighten the cover securely. (**Warning—**Do not add oxygen or ignite the sample if the high pressure decomposition device has been jarred, dropped, or tilted.) Admit oxygen slowly (to avoid blowing the oil from the cup) until a pressure is reached as indicated in the following table:

Capacity of High Pressure Decomposition Device, mL	Minimum Gauge Pressure, [A] kgf/cm^2 (atm)	Maximum Gauge Pressure, [A] kgf/cm^2 (atm)
300 to 350	39 (38)	41 (40)
350 to 400	36 (35)	38 (37)
400 to 450	31 (30)	33 (32)
450 to 500	28 (27)	30 (29)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures represent a safety requirement.

6.3 *Combustion*—Immerse the high pressure decomposition device in a cold distilled-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. (**Warning—**Do not go near the high pressure decomposition device until at least 20 s after firing.) Remove the high pressure decomposition device from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the high pressure decomposition device and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination and thoroughly clean the high pressure decomposition device before again putting it in use (Note 3).

6.4 *Collection of Sulfur Solution*— Rinse the interior of the high pressure decomposition device, the oil cup, and the inner surface of the high pressure decomposition device cover with a fine jet of water, and collect the washings in a 600-mL beaker having a mark to indicate 75 mL. Remove any precipitate in the high pressure decomposition device by means of a rubber policeman. Wash the base of the terminals until the washings are neutral to the indicator methyl red. Add 10 mL of saturated bromine water to the washings in the beaker. (The volume of the washings is normally in excess of 300 mL.) Place the sample cup in a 50-mL beaker. Add 5 mL of saturated bromine water, 2 mL of HCl, and enough water just to cover the cup. Heat the contents of the beaker to just below its boiling point for 3 or 4 min and add to the beaker containing the high pressure decomposition device washings. Wash the sample cup and the 50-mL beaker thoroughly with water. Remove any precipitate in the cup by means of a rubber policeman. Add the washings from the cup and the 50-mL beaker, and the precipitate, if any, to the high pressure decomposition device washings in the 600-mL beaker. Do not filter any of the washings, since filtering would remove any sulfur present as insoluble material.

6.5 *Determination of Sulfur*—Evaporate the combined washings to 200 mL on a hot plate or other source of heat. Adjust the heat to maintain slow boiling of the solution and add 10 mL of the $BaCl_2$ solution, either in a fine stream or dropwise. Stir the solution during the addition and for 2 min thereafter. Cover the beaker with a fluted watch glass and continue boiling slowly until the solution has evaporated to a volume approximately 75 mL as indicated by a mark on the beaker. Remove the beaker from the hot plate (or other source of heat) and allow it to cool for 1 h before filtering. Filter the supernatant liquid through an ashless, quantitative filter paper (Note 6). Wash the precipitate with water, first by decantation and then on the filter, until free from chloride. Transfer the paper and precipitate to a weighed crucible and dry (Note 7) at a low heat until the moisture has evaporated. Char the paper completely without igniting it, and finally ignite at a bright red heat until the residue is white in color. After ignition is complete, allow the crucible to cool at room temperature, and weigh.

NOTE 6—A weighed porcelain filter crucible (Selas type) of 5 to 9-µm porosity may be used in place of the filter paper. In this case the precipitate is washed free of chloride and then dried to constant weight at 500 ± 25°C.

NOTE 7—A satisfactory means of drying, charring, and igniting the paper and precipitate is to place the crucible containing the wet filter paper in a cold electric muffle furnace and to turn on the current. Drying, charring, and ignition usually will occur at the desired rate.

6.6 *Blank*—Make a blank determination whenever new reagents, white oil, or other low-sulfur combustible material are used. When running a blank on white oil, use 0.3 to 0.4 g and follow the normal procedure.

7. Calculation

7.1 Calculate the sulfur content of the sample as follows:

$$\text{Sulfur, weight percent} = (P - B)13.73/W \quad (1)$$

where:

P = grams of $BaSO_4$ obtained from sample,
B = grams of $BaSO_4$ obtained from blank, and
W = grams of sample used.

8. Report

8.1 Report the results of the test to the nearest 0.01 %.

9. Precision and Bias

9.1 The precision of this test is not known to have been obtained in accordance with currently accepted guidelines for example, in Research Report RR:D02-1007.

9.1.1 *Repeatability*—The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

9.1.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

Sulfur, weight percent	Repeatability	Reproducibility
0.1 to 0.5	0.04	0.05
0.5 to 1.0	0.06	0.09
1.0 to 1.5	0.08	0.15
1.5 to 2.0	0.12	0.25
2.0 to 5.0	0.18	0.27

NOTE 8—The precision shown in the above table does not apply to samples containing over 2 % chlorine because an added restriction on the amount of sample which can be ignited is imposed.

NOTE 9—This test method has been cooperatively tested only in the range of 0.1 to 5.0 % sulfur.

NOTE 10—The following information on the precision of this method has been developed by the Energy Institute (formerly known as the Institute of Petroleum):

(a) Results of duplicate tests should not differ by more than the following amounts:

Repeatability	Reproducibility
$0.016\ x + 0.06$	$0.037\ x + 0.13$

where x is the mean of duplicate test results.

(*b*) These precision values were obtained in 1960 by statistical examination of interlaboratory test results. No limits have been established for additive concentrates.

9.2 *Bias*—Results obtained in one laboratory by Test Method D129 on NIST Standard Reference Material Nos. 1620A, 1621C, and 1662B were found to be 0.05 mass % higher than the accepted reference values.

10. Quality Control

10.1 Confirm the performance of the instrument or the test procedure by analyzing a QC sample (see 5.9).

10.1.1 When QC/Quality Assurance (QA) protocols are already established in the testing facility, these may be used to confirm the reliability of the test result.

10.1.2 When there is no QC/QA protocol established in the testing facility, Appendix X1 can be used as the QC/QA system.

11. Keywords

11.1 high pressure decomposition device; sulfur

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL

X1.1 Confirm the performance of the instrument or the test procedure by analyzing a quality control (QC) sample.

X1.2 Prior to monitoring the measurement process, the user of the test method needs to determine the average value and control limits of the QC sample (see Practice D6299 and MNL 7).

X1.3 Record the QC results and analyze by control charts or other statistically equivalent techniques to ascertain the statistical control status of the total testing process (see Practice D6299 and MNL 7). Any out-of-control data should trigger investigation for root cause(s).

X1.4 In the absence of explicit requirements given in the test method, the frequency of QC testing is dependent on the criticality of the quality being measured, the demonstrated stability of the testing process, and customer requirements. Generally, a QC sample is analyzed each testing day with routine samples. The QC frequency should be increased if a large number of samples are routinely analyzed. However, when it is demonstrated that the testing is under statistical control, the QC testing frequency may be reduced. The QC sample precision should be checked against the ASTM method precision to ensure data quality.

X1.5 It is recommended that, if possible, the type of QC sample that is regularly tested be representative of the material routinely analyzed. An ample supply of QC sample material should be available for the intended period of use, and must be homogenous and stable under the anticipated storage conditions. See Practice D6299 and MNL 7 for further guidance on QC and control charting techniques.

STANDARD TEST METHOD FOR SULFATE ION IN WATER

(**19**) SD-516

(Identical with ASTM Specification D516-16.)

Standard Test Method for Sulfate Ion in Water

1. Scope

1.1 This turbidimetric test method covers the determination of sulfate in water in the range from 5 to 40 mg/L of sulfate ion (SO_4^{--}).

1.2 This test method was used successfully with drinking, ground, and surface waters. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

1.3 Former gravimetric and volumetric test methods have been discontinued. Refer to Appendix X1 for historical information.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D1066 Practice for Sampling Steam
D1129 Terminology Relating to Water
D1193 Specification for Reagent Water
D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water
D3370 Practices for Sampling Water from Closed Conduits
D4327 Test Method for Anions in Water by Suppressed Ion Chromatography
D5810 Guide for Spiking into Aqueous Samples
D5847 Practice for Writing Quality Control Specifications for Standard Test Methods for Water Analysis
E60 Practice for Analysis of Metals, Ores, and Related Materials by Spectrophotometry
E275 Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this standard, refer to Terminology D1129.

4. Summary of Test Method

4.1 Sulfate ion is converted to a barium sulfate suspension under controlled conditions. A solution containing glycerin and sodium chloride is added to stabilize the suspension and minimize interferences. The resulting turbidity is determined by a nephelometer, spectrophotometer, or photoelectric colorimeter and compared to a curve prepared from standard sulfate solutions.

5. Significance and Use

5.1 The determination of sulfate is important because it has been reported that when this ion is present in excess of about 250 mg/L in drinking water, it causes a cathartic action (especially in children) in the presence of sodium and magnesium, and gives a bad taste to the water.

5.2 Test Method D4327 ("Test Method of Anions in Water by Suppressed Ion Chromatography") may be used.

6. Interferences

6.1 Insoluble suspended matter in the sample must be removed. Dark colors that cannot be compensated for in the procedure interfere with the measurement of suspended barium sulfate ($BaSO_4$).

6.2 Polyphosphates as low as 1 mg/L will inhibit barium sulfate precipitation causing a negative interference. Phosphonates present in low concentrations, depending on the type of phosphonate, will also cause a negative interference. Silica in excess of 500 mg/L may precipitate along with the barium sulfate causing a positive interference. Chloride in excess of 5000 mg/L will cause a negative interference. Aluminum, polymers, and large quantities of organic material present in the test sample may cause the barium sulfate to precipitate nonuniformly. In the presence of organic matter certain bacteria may reduce sulfate to sulfide. To minimize the action of sulfate reducing bacteria, samples should be refrigerated at 4°C when the presence of such bacteria is suspected.

6.3 Although other ions normally found in water do not appear to interfere, the formation of the barium sulfate suspension is very critical. Determinations that are in doubt may be checked by a gravimetric method in some cases, or by the procedure suggested in Note 2.

7. Apparatus

7.1 *Photometer*—One of the following which are given in order of preference.

7.1.1 Nephelometer or turbidimeter;

7.1.2 Spectrophotometer for use at 420 nm with light path of 4 to 5 cm;

7.1.3 Filter photometer with a violet filter having a maximum near 420 nm and a light path of 4 to 5 cm.

7.2 *Stopwatch,* if the magnetic stirrer is not equipped with an accurate timer.

7.3 *Measuring Spoon,* capacity 0.2 to 0.3 mL.

7.4 Filter photometers and photometric practices prescribed in this test method shall conform to Practice E60; spectrophotometer practices shall conform to Practice E275.

8. Reagents and Materials

8.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water*—Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to Specification D1193, Type I. Other reagent water types may be used provided it is first ascertained that the water is of sufficiently high purity to permit its use without adversely affecting the precision and bias of the test method. Type II water was specified at the time of round robin testing of this test method.

8.3 *Barium Chloride*—Crystals of barium chloride ($BaCl_2{\cdot}2H_2O$) screened to 20 to 30 mesh. To prepare in the laboratory, spread crystals over a large watch glass, desiccate for 24 h, screen to remove any crystals that are not 20 to 30 mesh, and store in a clean, dry jar.

8.4 *Conditioning Reagent*—Place 30 mL of concentrated hydrochloric acid (HCl, sp gr 1.19), 300 mL reagent water, 100 mL 95 % ethanol or isopropanol and 75 g sodium chloride (NaCl) in a container. Add 50 mL glycerol and mix.

8.5 *Sulfate Solution, Standard* (1 mL = 0.100 mg SO_4^{--})—Dissolve 0.1479 g of anhydrous sodium sulfate (Na_2SO_4) in water, and dilute with water to 1 L in a volumetric flask. A purchased stock solution of adequate purity is also acceptable.

8.6 *Filter Paper*—Purchase suitable filter paper. Typically the filter papers have a pore size of 0.45-μm membrane. Material such as fine-textured, acid-washed, ashless paper, or glass fiber paper are acceptable. The user must first ascertain that the filter paper is of sufficient purity to use without adversely affecting the bias and precision of the test method.

9. Sampling

9.1 Collect the sample in accordance with Practice D1066, and Practices D3370, as applicable.

10. Calibration

10.1 Follow the procedure given in Section 11, using appropriate amounts of the standard sulfate solution prepared in accordance with 8.5 and prepare a calibration curve showing sulfate ion content in milligrams per litre plotted against the corresponding photometer readings (Note 1). Prepare standards by diluting with water 0.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0 mL of standard sulfate solution to 100-mL volumes in volumetric flasks. These solutions will have sulfate ion concentrations of 0.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0 mg/L (ppm), respectively.

NOTE 1—A separate calibration curve must be prepared for each photometer and a new curve must be prepared if it is necessary to change the cell, lamp, or filter, or if any other alterations of instrument or reagents are made. Check the curve with each series of tests by running two or more solutions of known sulfate concentrations.

11. Procedure

11.1 Filter (8.6) the sample if it is turbid through a 0.45-μm membrane and adjust the temperature to between 15 and 30°C.

11.2 Pipette into a 250-mL beaker 100 mL or less of the clear sample containing between 0.5 and 4 mg of sulfate ion (Note 2). Dilute to 100 mL with water if required, and add 5.0 mL of conditioning reagent (Note 1).

NOTE 2—The solubility of $BaSO_4$ is such that difficulty may be experienced in the determination of sulfate concentrations below about 5 mg/L (ppm). This can be overcome by concentrating the sample or by adding 5 mL of standard sulfate solution (1 mL = 0.100 mg SO_4^{--}) to the sample before diluting to 100 mL. This will add 0.5 mg SO_4 to the sample, which must be subtracted from the final result.

11.3 Mix in the stirring apparatus.

11.4 While the solution is being stirred, add a measured spoonful of $BaCl_2$ crystals (0.3 g) and begin timing immediately.

11.5 Stir exactly 1.0 min at constant speed.

NOTE 3—The stirring should be at a constant rate in all determinations. The use of a magnetic stirrer has been found satisfactory for this purpose.

11.6 Immediately after the stirring period has ended, pour solution into the cell and measure the turbidity at 30-s intervals for 4 min. Record the maximum reading obtained in the 4-min period.

11.7 If the sample contains color or turbidity, run a sample blank using the procedure 11.2 through 11.6 without the addition of the barium chloride.

11.8 If interferences are suspected, dilute the sample with an equal volume of water, and determine the sulfate concentration again. If the value so determined is one half that in the undiluted sample, interferences may be assumed to be absent.

NOTE 4—After dilution, if interferences are still determined to be present alternate methods should be used. It is up to the user to determine appropriate alternate methods.

12. Calculation

12.1 Convert the photometer readings obtained with the sample to milligrams per litre sulfate ion (SO_4^{--}) by use of the calibration curve described in Section 10.

13. Precision and Bias

13.1 The precision and bias data presented in this test method meet the requirements of Practice D2777 – 86.

13.2 The overall and single-operator precision of the test method, within its designated range, varies with the quantity being tested according to Table 1 for reagent water and Table 2 for drinking, ground, and surface waters.

13.2.1 Seven laboratories participated in the round robin at three levels in triplicate, making a total of 21 observations at each level for reagent water and for matrix water (drinking, ground, and surface water).

13.3 Recoveries of known amounts of sulfate from reagent water and drinking, ground, and surface waters are as shown in Table 3.

13.3.1 A table for estimating the bias of the test method through its applicable concentration range can be found in Table 4.

13.3.2 These collaborative test data were obtained on reagent grade water and natural waters. For other matrices, these data may not apply.

13.4 Precision and bias for this test method conforms to Practice D2777 – 86, which was in place at the time of collaborative testing. Under the allowances made in 1.4 of D2777 – 13, these precision and bias data do meet existing requirements for interlaboratory studies of Committee D19 test methods.

TABLE 1 Overall (S_T) and Single-Operator (S_O) Standard Deviations Against Mean Concentration for Interlaboratory Recovery of Sulfate from Reagent Water[A]

Mean Concentration ($\bar{x}$), mg/L	Standard Deviation, mg/L	
	S_T	S_O
6.6	0.5	0.1
20.4	1.0	0.4
63.7	2.5	1.3

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

TABLE 2 Overall (S_T) and Single-Operator (S_O) Standard Deviations Against Mean Concentration for Interlaboratory Recovery of Sulfate from Drinking, Ground, and Surface Water[A]

Mean Concentration ($\bar{x}$), mg/L	Standard Deviation, mg/L	
	S_T	S_O
6.9	0.7	0.5
20.2	2.2	1.8
63.3	4.5	1.6

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

TABLE 3 Determination of Bias[A]

	Amount Added, mg/L	Amount Found, mg/L	±Bias	±% Bias	Statistically Significant at 5 % Level (at ±0.05)
Reagent water	20.8	20.4	−0.4	−1.9 %	no
	63.9[A]	63.7[A]	−0.2	−0.2 %	no
	7.0	6.6	−0.4	−5.3 %	no
Drinking, ground and surface water	20.8	20.2	−0.6	−2.7 %	no
	63.9[A]	63.3[A]	−0.6	−0.9 %	no
	7.0	6.9	−0.1	−1.8 %	no

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

TABLE 4 Mean Sulfate Recovery Against Concentration Added with Overall Standard Deviation Shown for Interlaboratory Experimental Recovery of Sulfate from Reagent Water and Drinking, Ground, and Surface Water[A]

Sulfate Added, mg/L	Mean Sulfate Recovery ($\bar{x}$), mg/L	
	Reagent Water (S_T)	Matrix Water (S_O)
7.0	6.6 (0.5)	6.9 (0.7)
20.8	20.4 (1.0)	20.2 (2.2)
63.9	63.7 (2.5)	63.3 (4.5)

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

14. Quality Control (QC)

14.1 The following quality control information is recommended for the determination of sulfate ion in water.

14.2 *Calibration and Calibration Verification:*

14.2.1 Analyze at least three working standards containing concentrations of sulfate that bracket the expected sample concentration, prior to analysis of samples, to calibrate the instrument (see Section 11). The calibration correlation coefficient shall be equal to or greater than 0.990.

14.2.2 Verify instrument calibration after standardization by analyzing a standard at the concentration of one of the calibration standards. The concentration of a mid-range standard should fall within ±15 % of the known concentration. Analyze a calibration blank to verify system cleanliness.

14.2.3 If calibration cannot be verified, recalibrate the instrument.

14.2.4 It is recommended to analyze a continuing calibration blank (CCB) and continuing calibration verification (CCV) at a 10 % frequency. The results should fall within the expected precision of the method or ±15 % of the known concentration.

14.3 *Initial Demonstration of Laboratory Capability:*

14.3.1 If a laboratory has not performed the test before, or if there has been a major change in the measurement system, for example, new analyst, new instrument, and so forth, a precision and bias study must be performed to demonstrate laboratory capability.

14.3.2 Analyze seven replicates of a standard solution prepared from an Independent Reference Material containing a midrange concentration of sulfate. The matrix and chemistry of the solution should be equivalent to the solution used in the collaborative study. Each replicate must be taken through the complete analytical test method including any sample preservation and pretreatment steps.

14.3.3 Calculate the mean and standard deviation of the seven values and compare to the acceptable ranges of bias in Table 3. This study should be repeated until the recoveries are within the limits given in Table 1. If a concentration other than the recommended concentration is used, refer to Practice D5847 for information on applying the F test and t test in evaluating the acceptability of the mean and standard deviation.

14.4 *Laboratory Control Sample (LCS):*

14.4.1 To ensure that the test method is in control, prepare and analyze a LCS containing a known concentration of sulfate with each batch (laboratory-defined or 20 samples). The laboratory control samples for a large batch should cover the analytical range when possible. It is recommended, but not required to use a second source, if possible and practical for the LCS. The LCS must be taken through all of the steps of the analytical method including sample preservation and pretreatment. The result obtained for a mid-range LCS shall fall within ±15 % of the known concentration.

14.4.2 If the result is not within these limits, analysis of samples is halted until the problem is corrected, and either all the samples in the batch must be reanalyzed, or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

14.5 *Method Blank:*

14.5.1 Analyze a reagent water test blank with each laboratory-defined batch. The concentration of sulfate found in the blank should be less than 0.5 times the lowest calibration standard. If the concentration of sulfate is found above this level, analysis of samples is halted until the contamination is eliminated, and a blank shows no contamination at or above this level, or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

14.6 *Matrix Spike (MS):*

14.6.1 To check for interferences in the specific matrix being tested, perform a MS on at least one sample from each laboratory-defined batch by spiking an aliquot of the sample with a known concentration of sulfate and taking it through the analytical method.

14.6.2 The spike concentration plus the background concentration of sulfate must not exceed the high calibration standard. The spike must produce a concentration in the spiked sample that is 2 to 5 times the analyte concentration in the unspiked sample, or 10 to 50 times the detection limit of the test method, whichever is greater.

14.6.3 Calculate the percent recovery of the spike (P) using the following formula:

$$P = \left[A \left(V_s + V \right) - BV_s \right] / CV \quad (1)$$

where:

A = analyte known concentration (mg/L) in spiked sample,
B = analyte known concentration (mg/L) in unspiked sample,
C = known concentration (mg/L) of analyte in spiking solution,
V_s = volume (mL) of sample used, and
V = volume (mL) of spiking solution added.

14.6.4 The percent recovery of the spike shall fall within the limits, based on the analyte concentration, listed in Guide D5810, Table 1. If the percent recovery is not within these limits, a matrix interference may be present in the sample selected for spiking. Under these circumstances, one of the following remedies must be employed: the matrix interference must be removed, all samples in the batch must be analyzed by a test method not affected by the matrix interference, or the results must be qualified with an indication that they do not fall within the performance criteria of the guide.

NOTE 5—Acceptable spike recoveries are dependent on the concentration of the component of interest. See Test Method D5810 for additional information.

14.7 *Duplicate:*

14.7.1 To check the precision of sample analyses, analyze a sample in duplicate with each laboratory-defined batch. If the concentration of the analyte is less than five times the detection limit for the analyte, a matrix spike duplicate (MSD) should be used.

14.7.2 Calculate the standard deviation of the duplicate values and compare to the precision in the collaborative study using an F test. Refer to 6.4.4 of Practice D5847 for information on applying the F test.

14.7.3 If the result exceeds the precision limit, the batch must be reanalyzed or the results must be qualified with an indication that they do not fall within the performance criteria of the test method.

14.8 *Independent Reference Material (IRM):*

14.8.1 In order to verify the quantitative value produced by the test method, analyze an Independent Reference Material (IRM) submitted as a regular sample (if practical) to the laboratory at least once per quarter. The concentration of the IRM should be in the concentration mid-range for the method chosen. The value obtained must fall within the control limits established by the laboratory.

15. Keywords

15.1 drinking water; ground water; sulfate; surface water; turbidimetric

APPENDIX

(Nonmandatory Information)

X1. RATIONALE FOR DISCONTINUATION OF METHODS

X1.1 *Gravimetric:*

X1.1.1 This test method was discontinued in 1988. The test method may be found in the *1988 Annual Book of ASTM Standards*, Vol 11.01. The test method was originally issued in 1938.

X1.1.2 This test method covers the determination of sulfate in water and wastewater. Samples containing from 20 to 100 mg/L of sulfate may be analyzed.

X1.1.3 Sulfate is precipitated and weighted as barium sulfate after removal of silica and other insoluble matter.

X1.1.4 This test method was discontinued because there were insufficient laboratories interested in participating in another collaborative study to obtain the necessary precision and bias as required by Practice D2777.

X1.2 *Volumetric:*

X1.2.1 This test method was discontinued in 1988. The test method may be found in the *1988 Annual Book of ASTM Standards*, Vol 11.01. The test method was originally issued in 1959 as a non-referee method, and made the primary method in the 1980 issue of Test Method D516.

X1.2.2 This test method covers the determination of sulfate in industrial water. Samples containing from 5 to 1000 mg/L of sulfate may be analyzed.

X1.2.3 Sulfate is titrated in an alcoholic solution under controlled acid conditions with a standard barium chloride solution using thorin as the indicator.

X1.2.4 This test method was discontinued because there were insufficient laboratories interested in participating in another collaborative study to obtain the necessary precision and bias as required by Practice D2777.

STANDARD TEST METHOD FOR CHLORINE IN NEW AND USED PETROLEUM PRODUCTS (HIGH PRESSURE DECOMPOSITION DEVICE METHOD)

(19)

SD-808

(Identical with ASTM Specification D808-16.)

Standard Test Method for Chlorine in New and Used Petroleum Products (High Pressure Decomposition Device Method)

1. Scope

1.1 This test method covers the determination of chlorine in lubricating oils and greases, including new and used lubricating oils and greases containing additives, and in additive concentrates. Its range of applicability is 0.1 m% to 50 m% chlorine. The procedure assumes that compounds containing halogens other than chlorine will not be present.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.2.1 The preferred units are mass percent.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Attention is called to specific warning statements incorporated in the test method.

2. Referenced Documents

2.1 *ASTM Standards:*

D1193 Specification for Reagent Water

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products

D6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance

3. Summary of Test Method

3.1 The sample is oxidized by combustion in a high pressure decomposition device containing oxygen under pressure. (**Warning—**Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the high pressure decomposition device, or a blow-out, provided the high pressure decomposition device is of proper design and construction and in good mechanical condition. It is desirable, however, that the high pressure decomposition device be enclosed in a shield of steel plate at least 13 mm (½ in.) thick, or equivalent protection be provided against unforeseeable contingencies.) The chlorine compounds thus liberated are absorbed in a sodium carbonate solution and the amount of chlorine present is determined gravimetrically by precipitation as silver chloride.

4. Significance and Use

4.1 This test method may be used to measure the level of chlorine-containing compounds in petroleum products. This knowledge can be used to predict performance or handling characteristics of the product in question.

4.2 This test method can also serve as a qualitative tool for the presence or non-detection of chlorine in petroleum products. In light of the efforts in the industry to prepare chlorine free products, this test method would provide information regarding the chlorine levels, if any, in such products.

5. Apparatus

5.1 *High Pressure Decomposition Device,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the high pressure decomposition device may be readily achieved. The inner surface of the high pressure decomposition device may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the high pressure decomposition device assembly, such as the head gasket and lead-wire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the high pressure decomposition device.

5.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 g to 11 g.

5.3 *Firing Wire,* platinum, No. 26 B & S gage 0.41 (16 thou), 27 SWG or equivalent.

5.4 *Ignition Circuit,* capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

5.4.1 The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

5.5 *Nylon Sewing Thread, or Cotton Wicking,* white.

5.6 *Filter Crucible,* fritted-glass, 30 mL capacity, medium porosity.

6. Reagents and Materials

6.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II or III of Specification D1193.

6.3 *Nitric Acid* (1 + 1)—Mix equal volumes of concentrated nitric acid (HNO_3, sp gr 1.42) and water.

6.4 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 41 kgf/cm^2 (40 atmos). (**Warning—**Oxygen vigorously accelerates combustion.)

6.5 *Silver Nitrate Solution* (50 g $AgNO_3$/L)—Dissolve 50 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

6.6 *Sodium Carbonate Solution* (50 g Na_2CO_3/L)—Dissolve 50 g of anhydrous Na_2CO_3, 58.5 g of $Na_2CO_3 \cdot H_2O$, or 135 g of $Na_2CO_3 \cdot 10\ H_2O$ in water and dilute to 1 L.

6.7 *White Oil,* refined.

6.8 *Quality Control (QC) Samples,* preferably are portions of one or more liquid petroleum materials that are stable and representative of the samples of interest. These QC samples can be used to check the validity of the testing process as described in Section 10.

6.9 *Methyl Red Indicator Solution*—Dissolve 0.1 g of methyl red indicator solid in 100 mL of water.

7. Sampling

7.1 Take samples in accordance with the instructions in Practices D4057 or D4177.

7.2 Take care that the sample is thoroughly representative of the material to be tested and that the portion of the sample used for the test is thoroughly representative of the whole sample.

TABLE 1 Quantities of Sample and White Oil

Chlorine Content, m%	Weight of Sample, g	Weight of White Oil, g
2 and under	0.8	0.0
Above 2 to 5, incl.	0.4	0.4
Above 5 to 10, incl.	0.2	0.6
Above 10 to 20, incl.	0.1	0.7
Above 20 to 50, incl.	0.05	0.7

8. Procedure

8.1 *Preparation of High Pressure Decomposition Device and Sample*—Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Insert into the coil a nylon thread, or wisp of cotton, of such length that one end will extend into the sample cup. Place about 5 mL of Na_2CO_3 solution in the high pressure decomposition device and by means of a rubber policeman, wet the interior surface of the high pressure decomposition device, including the head, as thoroughly as possible. Introduce into the sample cup the quantities of sample and white oil (Note 1). (**Warning—**Do not use more than 1 g total of sample and white oil or other chlorine free combustible material) specified in Table 1. Do not add oxygen or ignite the sample if the high pressure decomposition device has been jarred, dropped, or tilted), weighing the sample to the nearest 0.2 mg.) When white oil is used, stir the mixture with a short length of quartz rod and allow the rod to remain in the sample cup during the combustion.

8.1.1 After repeated use of the high pressure decomposition device for chlorine determination, a film may be noticed on the inner surface. This dullness can be removed by periodic polishing of the high pressure decomposition device. A satisfactory method for doing this is to rotate the high pressure decomposition device in a lathe at about 300 r/min and polish the inside with Grit No. 2/0 or equivalent paper coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before using the high pressure decomposition device wash it with soap and water to remove oil or paste left from the polishing operation. High pressure decomposition devices with porous or pitted surfaces should never be used because of the tendency to retain chlorine from sample to sample.

8.1.2 When the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil. (**Warning—**Do not use more than 1 g total of sample and white oil or other chlorine-free combustible material.)

TABLE 2 Gage Pressures

Capacity of High Pressure Decomposition Device, mL	Minimum Gage Pressure,[A] kgf/cm² (atm)	Maximum Gage Pressure,[A] kgf/cm² (atm)
300 to 350	39 (38)	41 (40)
350 to 400	36 (35)	38 (37)
400 to 450	31 (30)	33 (32)
450 to 500	28 (27)	30 (29)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion, and the *maximum pressures represent a safety requirement.*

NOTE 1—The practice of running alternately high and low samples in chlorine content shall be avoided whenever possible. It is difficult to rinse the last traces of chlorine from the walls of the high pressure decomposition device and the tendency for residual chlorine to carry over from sample to sample has been observed in a number of laboratories. When a sample high in chlorine has preceded one low in chlorine content, the test on the low-chlorine sample shall be repeated and one or both of the low values thus obtained can be considered suspect if they do not agree within the limits of repeatability of this test method.

8.2 *Addition of Oxygen*—Place the sample cup in position and arrange the nylon thread, or wisp of cotton, so that the end dips into the sample. Assemble the high pressure decomposition device and tighten the cover securely. Admit oxygen slowly (to avoid blowing the oil from the cup) until a pressure is reached as indicated in Table 2. (**Warning—**Do not add oxygen or ignite the sample if the high pressure decomposition device has been jarred, dropped, or tilted.)

8.3 *Combustion*—Immerse the high pressure decomposition device in a cold water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the high pressure decomposition device from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the high pressure decomposition device and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the high pressure decomposition device before again putting it in use (8.1.1).

8.4 *Collection of Chlorine Solution*—Rinse the interior of the high pressure decomposition device, the sample cup, and the inner surface of the high pressure decomposition device cover with a fine jet of water, and collect the washings in a 600 mL beaker. Scrub the interior of the high pressure decomposition device and the inner surface of the high pressure decomposition device cover with a rubber policeman. Wash the base of the terminals until the washings are neutral to the indicator methyl red. (The volume of the washings is normally in excess of 300 mL.) Take special care not to lose any wash water.

8.5 *Determination of Chlorine*—Acidify the solution by adding HNO_3 (1 + 1) drop by drop until acid to methyl red. Add an excess of 2 mL of the HNO_3 solution. Filter through a qualitative paper (if the solution is cloudy, the presence of lead chloride ($PbCl_2$) is indicated and the solution should be brought to a boil before filtering) and collect in a second 600 mL beaker. Heat the solution to about 60 °C (140 °F) and, while protecting the solution from strong light, add gradually, while stirring, 5 mL of $AgNO_3$ solution. Heat to incipient boiling and retain at this temperature until the supernatant liquid becomes clear. Test to ensure complete precipitation by adding a few drops of the $AgNO_3$ solution. If more precipitation takes place, repeat the above steps which have involved heating, stirring, and addition of $AgNO_3$, as often as necessary, until the additional drops of $AgNO_3$ produce no turbidity in the clear, supernatant liquid. Allow the beaker and contents to stand in a dark place for at least an hour. Filter the precipitate by suction on a weighed fritted-glass filter crucible. Wash the precipitate with water containing 2 mL of HNO_3 (1 + 1)/L. Dry the crucible and precipitate at 110 °C for 1 h. Cool in a desiccator, and weigh.

NOTE 2—If no precipitate is visible at this stage after addition of silver nitrate, this may be taken as an indication of non-detectable quantities of chlorine in the test sample above this test method's detection limit (0.1 m%). The test can be considered as completed at this stage.

8.6 *Blank*—Make a blank determination with 0.7 g to 0.8 g of white oil by following the normal procedure but omitting the sample (Note 3). Repeat this blank whenever new batches of reagents or white oil are used. The blank must not exceed 0.03 m% chlorine based upon the weight of the white oil.

NOTE 3—This procedure measures chlorine in the white oil and in the reagents used, as well as that introduced from contamination.

9. Calculation

9.1 Calculate the chlorine content of the sample as follows:

$$\text{Chlorine, mass\%} = \left[(P - B) \times 24.74\right]/W \qquad (1)$$

where:

P = grams of AgCl obtained from the sample,
B = grams of AgCl obtained from the blank, and
W = grams of sample used.

10. Quality Control

10.1 Confirm the performance of the instrument or the test procedure by analyzing a QC sample (see 6.8).

10.1.1 When QC/Quality Assurance (QA) protocols are already established in the testing facility, these may be used to confirm the reliability of the test result.

10.1.2 When there is no QC/QA protocol established in the testing facility, Appendix X1 can be used as the QC/QA system.

11. Report

11.1 Report the results to the nearest 0.1 m%.

11.2 If there is absence of a visible precipitate in 8.5, report the results as non-detectable above the detection limits (0.1 m%) of this test method.

12. Precision and Bias

12.1 The precision of this test method is not known to have been obtained in accordance with currently accepted guidelines (for example, in Committee D02 Research Report RR:D02-1007, Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants).

12.2 The precision of this test method as obtained by statistical examination of interlaboratory test results is as follows:

12.2.1 *Repeatability*—The difference between successive test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty:

Chlorine, m%	Repeatability
0.1 to 1.9	0.07
2.0 to 5.0	0.15
Above 5.0	3 % of amount present

12.2.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty:

Chlorine, m%	Reproducibility
0.1 to 1.9	0.10
2.0 to 5.0	0.30
Above 5.0	5 % of the amount present

12.3 *Bias:*

12.3.1 Cooperative data indicate that deviations of test results from the true chlorine content are of the same order of magnitude as the reproducibility.

12.3.2 It is not practicable to specify the bias of this test method for measuring chlorine because the responsible subcommittee, after diligent search, was unable to attract volunteers for an interlaboratory study.

13. Keywords

13.1 chlorine; high pressure decomposition device

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL

X1.1 Confirm the performance of the instrument or the test procedure by analyzing a QC sample.

X1.2 Prior to monitoring the measurement process, the user of the method needs to determine the average value and control limits of the QC sample (see Practice D6299 and MNL 7).[1]

X1.3 Record the QC results and analyze by control charts or other statistically equivalent techniques to ascertain the statistical control status of the total testing process (see Practice D6299 and MNL 7).[1] Any out-of-control data should trigger investigation for root cause(s).

X1.4 In the absence of explicit requirements given in the test method, the frequency of QC testing is dependent on the criticality of the quality being measured, the demonstrated stability of the testing process, and customer requirements. Generally, a QC sample is analyzed each testing day with routine samples. The QC frequency should be increased if a large number of samples are routinely analyzed. However, when it is demonstrated that the testing is under statistical control, the QC testing frequency may be reduced. The QC sample precision should be checked against the ASTM method precision to ensure data quality.

X1.5 It is recommended that, if possible, the type of QC sample that is regularly tested be representative of the material routinely analyzed. An ample supply of QC sample material should be available for the intended period of use, and must be homogenous and stable under the anticipated storage conditions. See Practice D6299 and MNL 7[5] for further guidance on QC and Control Charting techniques.

[1] MNL 7, *Manual on Presentation of Data Control Chart Analysis*, 6th ed., ASTM International, W. Conshohocken, PA.

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STANDARD PRACTICE FOR LIQUID PENETRANT EXAMINATION FOR GENERAL INDUSTRY

SE-165/SE-165M

(Identical with ASTM Specification E165/E165M-12.)

Standard Practice for Liquid Penetrant Examination for General Industry

1. Scope

1.1 This practice covers procedures for penetrant examination of materials. Penetrant testing is a nondestructive testing method for detecting discontinuities that are open to the surface such as cracks, seams, laps, cold shuts, shrinkage, laminations, through leaks, or lack of fusion and is applicable to in-process, final, and maintenance testing. It can be effectively used in the examination of nonporous, metallic materials, ferrous and nonferrous metals, and of nonmetallic materials such as nonporous glazed or fully densified ceramics, as well as certain nonporous plastics, and glass.

1.2 This practice also provides a reference:

1.2.1 By which a liquid penetrant examination process recommended or required by individual organizations can be reviewed to ascertain its applicability and completeness.

1.2.2 For use in the preparation of process specifications and procedures dealing with the liquid penetrant testing of parts and materials. Agreement by the customer requesting penetrant inspection is strongly recommended. All areas of this practice may be open to agreement between the cognizant engineering organization and the supplier, or specific direction from the cognizant engineering organization.

1.2.3 For use in the organization of facilities and personnel concerned with liquid penetrant testing.

1.3 This practice does not indicate or suggest criteria for evaluation of the indications obtained by penetrant testing. It should be pointed out, however, that after indications have been found, they must be interpreted or classified and then evaluated. For this purpose there must be a separate code, standard, or a specific agreement to define the type, size, location, and direction of indications considered acceptable, and those considered unacceptable.

1.4 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D129 Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)
E516 Practice for Testing Thermal Conductivity Detectors Used in Gas Chromatography
D808 Test Method for Chlorine in New and Used Petroleum Products (High Pressure Decomposition Device Method)
D1193 Specification for Reagent Water
D1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)
D4327 Test Method for Anions in Water by Suppressed Ion Chromatography
E433 Reference Photographs for Liquid Penetrant Inspection
E543 Specification for Agencies Performing Nondestructive Testing
E1208 Practice for Fluorescent Liquid Penetrant Testing Using the Lipophilic Post-Emulsification Process
E1209 Practice for Fluorescent Liquid Penetrant Testing Using the Water-Washable Process
E1210 Practice for Fluorescent Liquid Penetrant Testing Using the Hydrophilic Post-Emulsification Process
E1219 Practice for Fluorescent Liquid Penetrant Testing Using the Solvent-Removable Process
E1220 Practice for Visible Penetrant Testing Using Solvent-Removable Process
E1316 Terminology for Nondestructive Examinations
E1417 Practice for Liquid Penetrant Testing

E1418 Practice for Visible Penetrant Testing Using the Water-Washable Process
E2297 Guide for Use of UV-A and Visible Light Sources and Meters used in the Liquid Penetrant and Magnetic Particle Methods

2.2 *ASNT Document:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification
ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

2.4 *APHA Standard:*

429 Method for the Examination of Water and Wastewater

2.5 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Test Personnel

2.6 *SAE Standards:*

AMS 2644 Inspection Material, Penetrant
QPL-AMS-2644 Qualified Products of Inspection Materials, Penetrant

3. Terminology

3.1 The definitions relating to liquid penetrant examination, which appear in Terminology E1316, shall apply to the terms used in this practice.

4. Summary of Practice

4.1 Liquid penetrant may consist of visible or fluorescent material. The liquid penetrant is applied evenly over the surface being examined and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed. A developer is applied to draw the entrapped penetrant out of the discontinuity and stain the developer. The test surface is then examined to determine the presence or absence of indications.

NOTE 1—The developer may be omitted by agreement between the contracting parties.

NOTE 2—Fluorescent penetrant examination shall not follow a visible penetrant examination unless the procedure has been qualified in accordance with 10.2, because visible dyes may cause deterioration or quenching of fluorescent dyes.

4.2 Processing parameters, such as surface precleaning, penetrant dwell time and excess penetrant removal methods, are dependent on the specific materials used, the nature of the part under examination, (that is, size, shape, surface condition, alloy) and type of discontinuities expected.

5. Significance and Use

5.1 Liquid penetrant testing methods indicate the presence, location and, to a limited extent, the nature and magnitude of the detected discontinuities. Each of the various penetrant methods has been designed for specific uses such as critical service items, volume of parts, portability or localized areas of examination. The method selected will depend accordingly on the design and service requirements of the parts or materials being tested.

6. Classification of Penetrant Materials and Methods

6.1 Liquid penetrant examination methods and types are classified in accordance with MIL-I-25135 and AMS 2644 as listed in Table 1.

6.2 *Fluorescent Penetrant Testing (Type 1)*—Fluorescent penetrant testing utilizes penetrants that fluoresce brilliantly when excited by black light (UVA). The sensitivity of fluorescent penetrants depends on their ability to be retained in the various size discontinuities during processing, and then to bleed out into the developer coating and produce indications that will fluoresce. Fluorescent indications are many times brighter than their surroundings when viewed under appropriate black light illumination.

6.3 *Visible Penetrant Testing (Type 2)*—Visible penetrant testing uses a penetrant that can be seen in visible light. The penetrant is usually red, so that resultant indications produce a definite contrast with the white background of the developer. Visible penetrant indications must be viewed under adequate white light.

7. Materials

7.1 *Liquid Penetrant Testing Materials* consist of fluorescent or visible penetrants, emulsifiers (oil-base and water-base), removers (water and solvent), and developers (dry powder, aqueous and nonaqueous). A family of liquid penetrant examination materials consists of the applicable penetrant and emulsifier, as recommended by the manufacturer. Any liquid penetrant, remover and developer listed in QPL-25135/QPL-AMS2644 can be used, regardless of the manufacturer. Intermixing of penetrants and emulsifiers from different manufacturers is prohibited.

NOTE 3—Refer to 9.1 for special requirements for sulfur, halogen and alkali metal content.

NOTE 4—While approved penetrant materials will not adversely affect common metallic materials, some plastics or rubbers may be swollen or stained by certain penetrants.

7.2 *Penetrants:*

TABLE 1 Classification of Penetrant Examination Types and Methods

Type I—Fluorescent Penetrant Examination
Method A—Water-washable (see Test Method E1209)
Method B—Post-emulsifiable, lipophilic (see Test Method E1208)
Method C—Solvent removable (see Test Method E1219)
Method D—Post-emulsifiable, hydrophilic (see Test Method E1210)
Type II—Visible Penetrant Examination
Method A—Water-washable (see Test Method E1418)
Method C—Solvent removable (see Test Method E1220)

7.2.1 *Post-Emulsifiable Penetrants* are insoluble in water and cannot be removed with water rinsing alone. They are formulated to be selectively removed from the surface using a separate emulsifier. Properly applied and given a proper emulsification time, the emulsifier combines with the excess surface penetrant to form a water-washable mixture, which can be rinsed from the surface, leaving the surface free of excessive fluorescent background. Proper emulsification time must be experimentally established and maintained to ensure that over-emulsification does not result in loss of indications.

7.2.2 *Water-Washable Penetrants* are formulated to be directly water-washable from the surface of the test part, after a suitable penetrant dwell time. Because the emulsifier is "built-in," water-washable penetrants can be washed out of discontinuities if the rinsing step is too long or too vigorous. It is therefore extremely important to exercise proper control in the removal of excess surface penetrant to ensure against overwashing. Some penetrants are less resistant to overwashing than others, so caution should be exercised.

7.2.3 *Solvent-Removable Penetrants* are formulated so that excess surface penetrant can be removed by wiping until most of the penetrant has been removed. The remaining traces should be removed with the solvent remover (see 8.6.4). To prevent removal of penetrant from discontinuities, care should be taken to avoid the use of excess solvent. Flushing the surface with solvent to remove the excess penetrant is prohibited as the penetrant indications could easily be washed away.

7.3 *Emulsifiers:*

7.3.1 *Lipophilic Emulsifiers* are oil-miscible liquids used to emulsify the post-emulsified penetrant on the surface of the part, rendering it water-washable. The individual characteristics of the emulsifier and penetrant, and the geometry/surface roughness of the part material contribute to determining the emulsification time.

7.3.2 *Hydrophilic Emulsifiers* are water-miscible liquids used to emulsify the excess post-emulsified penetrant on the surface of the part, rendering it water-washable. These water-base emulsifiers (detergent-type removers) are supplied as concentrates to be diluted with water and used as a dip or spray. The concentration, use and maintenance shall be in accordance with manufacturer's recommendations.

7.3.2.1 Hydrophilic emulsifiers function by displacing the excess penetrant film from the surface of the part through detergent action. The force of the water spray or air/mechanical agitation in an open dip tank provides the scrubbing action while the detergent displaces the film of penetrant from the part surface. The individual characteristics of the emulsifier and penetrant, and the geometry and surface roughness of the part material contribute to determining the emulsification time. Emulsification concentration shall be monitored weekly using a suitable refractometer.

7.4 *Solvent Removers*—Solvent removers function by dissolving the penetrant, making it possible to wipe the surface clean and free of excess penetrant.

7.5 *Developers*—Developers form a translucent or white absorptive coating that aids in bringing the penetrant out of surface discontinuities through blotting action, thus increasing the visibility of the indications.

7.5.1 *Dry Powder Developers*—Dry powder developers are used as supplied, that is, free-flowing, non-caking powder (see 8.8.1). Care should be taken not to contaminate the developer with fluorescent penetrant, as the contaminated developer specks can appear as penetrant indications.

7.5.2 *Aqueous Developers*—Aqueous developers are normally supplied as dry powder particles to be either suspended (water suspendable) or dissolved (water soluble) in water. The concentration, use and maintenance shall be in accordance with manufacturer's recommendations. Water soluble developers shall not be used with Type 2 penetrants or Type 1, Method A penetrants.

NOTE 5—Aqueous developers may cause stripping of indications if not properly applied and controlled. The procedure should be qualified in accordance with 10.2.

7.5.3 *Nonaqueous Wet Developers*—Nonaqueous wet developers are supplied as suspensions of developer particles in a nonaqueous solvent carrier ready for use as supplied. Nonaqueous, wet developers are sprayed on to form a thin coating on the surface of the part when dried. This thin coating serves as the developing medium.

NOTE 6—This type of developer is intended for application by spray only.

7.5.4 *Liquid Film Developers* are solutions or colloidal suspensions of resins/polymer in a suitable carrier. These developers will form a transparent or translucent coating on the surface of the part. Certain types of film developer may be stripped from the part and retained for record purposes (see 8.8.4).

8. Procedure

8.1 The following processing parameters apply to both fluorescent and visible penetrant testing methods.

8.2 *Temperature Limits*—The temperature of the penetrant materials and the surface of the part to be processed shall be between 40° and 125°F [4° and 52°C] or the procedure must be qualified at the temperature used as described in 10.2.

8.3 *Examination Sequence*—Final penetrant examination shall be performed after the completion of all operations that could cause surface-connected discontinuities or operations that could expose discontinuities not previously open to the surface. Such operations include, but are not limited to, grinding, welding, straightening, machining, and heat treating. Satisfactory inspection results can usually be obtained on surfaces in the as-welded, as-rolled, as-cast, as-forged, or ceramics in the densified condition.

8.3.1 *Surface Treatment*—Final penetrant examination may be performed prior to treatments that can smear the surface but not by themselves cause surface discontinuities. Such treatments include, but are not limited to, vapor blasting, deburring, sanding, buffing, sandblasting, or lapping. Performance of final penetrant examination after such surface treatments necessitates that the part(s) be etched to remove smeared metal from the surface prior to testing unless otherwise agreed by the contracting parties. Note that final penetrant examination shall always precede surface peening.

NOTE 7—Sand or shot blasting can close discontinuities so extreme care should be taken to avoid masking discontinuities. Under certain circumstances, however, grit blasting with certain air pressures and/or mediums may be acceptable without subsequent etching when agreed by the contracting parties.

NOTE 8—Surface preparation of structural or electronic ceramics for penetrant testing by grinding, sand blasting and etching is not recommended because of the potential for damage.

8.4 *Precleaning*—The success of any penetrant examination procedure is greatly dependent upon the surrounding surface and discontinuity being free of any contaminant (solid or liquid) that might interfere with the penetrant process. All parts or areas of parts to be examined must be clean and dry before the penetrant is applied. If only a section of a part, such as a weld, including the heat affected zone is to be examined, all contaminants shall be removed from the area being examined as defined by the contracting parties. "Clean" is intended to mean that the surface must be free of rust, scale, welding flux, weld spatter, grease, paint, oily films, dirt, and so forth, that might interfere with the penetrant process. All of these contaminants can prevent the penetrant from entering discontinuities (see Annex on Cleaning of Parts and Materials).

8.4.1 *Drying after Cleaning*—It is essential that the surface of parts be thoroughly dry after cleaning, since any liquid residue will hinder the entrance of the penetrant. Drying may be accomplished by warming the parts in drying ovens, with infrared lamps, forced hot air, or exposure to ambient temperature.

NOTE 9—Residues from cleaning processes such as strong alkalies, pickling solutions and chromates, in particular, may adversely react with the penetrant and reduce its sensitivity and performance.

8.5 *Penetrant Application*—After the part has been cleaned, dried, and is within the specified temperature range, the penetrant is applied to the surface to be examined so that the entire part or area under examination is completely covered with penetrant. Application methods include dipping, brushing, flooding, or spraying. Small parts are quite often placed in suitable baskets and dipped into a tank of penetrant. On larger parts, and those with complex geometries, penetrant can be applied effectively by brushing or spraying. Both conventional and electrostatic spray guns are effective means of applying liquid penetrants to the part surfaces. Not all penetrant materials are suitable for electrostatic spray applications, so tests should be conducted prior to use. Electrostatic spray application can eliminate excess liquid build-up of penetrant on the part, minimize overspray, and minimize the amount of penetrant entering hollow-cored passages which might serve as penetrant reservoirs, causing severe bleedout problems during examination. Aerosol sprays are conveniently portable and suitable for local application.

NOTE 10—With spray applications, it is important that there be proper ventilation. This is generally accomplished through the use of a properly designed spray booth and exhaust system.

8.5.1 *Penetrant Dwell Time*—After application, allow excess penetrant to drain from the part (care should be taken to prevent pools of penetrant from forming on the part), while allowing for proper penetrant dwell time (see Table 2). The length of time the penetrant must remain on the part to allow proper penetration should be as recommended by the penetrant manufacturer. Table 2, however, provides a guide for selection of penetrant dwell times for a variety of materials, forms, and types of discontinuities. Unless otherwise specified, the dwell time shall not exceed the maximum recommended by the manufacturer.

8.6 *Penetrant Removal*

8.6.1 *Water Washable (Method A):*

8.6.1.1 *Removal of Water Washable Penetrant*—After the required penetrant dwell time, the excess penetrant on the surface being examined must be removed with water. It can be removed manually with a coarse spray or wiping the part surface with a dampened rag, automatic or semi-automatic water-spray equipment, or by water immersion. For immersion rinsing, parts are completely immersed in the water bath with air or mechanical agitation.

(a) The temperature of the water shall be maintained within the range of 50° to 100°F [10° to 38°C].

(b) Spray-rinse water pressure shall not exceed 40 psi [275 kPa]. When hydro-air pressure spray guns are used, the air pressure should not exceed 25 psi [172 kPa].

NOTE 11—Overwashing should be avoided. Excessive washing can cause penetrant to be washed out of discontinuities. With fluorescent penetrant methods perform the manual rinsing operation under black light so that it can be determined when the surface penetrant has been adequately removed.

TABLE 2 Recommended Minimum Dwell Times

Material	Form	Type of Discontinuity	Dwell Times[A] (minutes)	
			Penetrant[B]	Developer[C]
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	castings and welds	cold shuts, porosity, lack of fusion, cracks (all forms)	5	10
	wrought materials—extrusions, forgings, plate	laps, cracks (all forms)	10	10
Carbide-tipped tools		lack of fusion, porosity, cracks	5	10
Plastic	all forms	cracks	5	10
Glass	all forms	cracks	5	10
Ceramic	all forms	cracks, porosity	5	10

[A] For temperature range from 50° to 125°F [10° to 52°C]. For temperatures between 40° and 50°F [4.4° and 10°C], recommend a minimum dwell time of 20 minutes.
[B] Maximum penetrant dwell time in accordance with 8.5.1.
[C] Development time begins as soon as wet developer coating has dried on surface of parts (recommended minimum). Maximum development time in accordance with 8.8.5.

8.6.1.2 *Removal by Wiping (Method C)*—After the required penetrant dwell time, the excess penetrant is removed by wiping with a dry, clean, lint-free cloth/towel. Then use a clean lint-free cloth/towel lightly moistened with water or solvent to remove the remaining traces of surface penetrant as determined by examination under black light for fluorescent methods and visible light for visible methods.

8.6.2 *Lipophilic Emulsification (Method B):*

8.6.2.1 *Application of Lipophilic Emulsifier*—After the required penetrant dwell time, the excess penetrant on the part must be emulsified by immersing or flooding the parts with the required emulsifier (the emulsifier combines with the excess surface penetrant and makes the mixture removable by water rinsing). Lipophilic emulsifier shall not be applied by spray or brush and the part or emulsifier shall not be agitated while being immersed. After application of the emulsifier, the parts shall be drained and positioned in a manner that prevents the emulsifier from pooling on the part(s).

8.6.2.2 *Emulsification Time*—The emulsification time begins as soon as the emulsifier is applied. The length of time that the emulsifier is allowed to remain on a part and in contact with the penetrant is dependent on the type of emulsifier employed and the surface roughness. Nominal emulsification time should be as recommended by the manufacturer. The actual emulsification time must be determined experimentally for each specific application. The surface finish (roughness) of the part is a significant factor in the selection of and in the emulsification time of an emulsifier. Contact time shall be kept to the minimum time to obtain an acceptable background and shall not exceed three minutes.

8.6.2.3 *Post Rinsing*—Effective post rinsing of the emulsified penetrant from the surface can be accomplished using either manual, semi-automated, or automated water immersion or spray equipment or combinations thereof.

8.6.2.4 *Immersion*—For immersion post rinsing, parts are completely immersed in the water bath with air or mechanical agitation. The amount of time the part is in the bath should be the minimum required to remove the emulsified penetrant. In addition, the temperature range of the water should be 50 to 100°F [10 to 38°C]. Any necessary touch-up rinse after an immersion rinse shall meet the requirements of 8.6.2.5.

8.6.2.5 *Spray Post Rinsing*—Effective post rinsing following emulsification can also be accomplished by either manual or automatic water spray rinsing. The water temperature shall be between 50 and 100°F [10 and 38°C]. The water spray pressure shall not exceed 40 psi [275 kPa] when manual spray guns are used. When hydro-air pressure spray guns are used, the air pressure should not exceed 25 psi [172 kPa].

8.6.2.6 *Rinse Effectiveness*—If the emulsification and final rinse step is not effective, as evidenced by excessive residual surface penetrant after emulsification and rinsing; thoroughly reclean and completely reprocess the part.

8.6.3 *Hydrophilic Emulsification (Method D):*

8.6.3.1 *Application of Hydrophilic Remover*—Following the required penetrant dwell time, the parts may be prerinsed with water prior to the application of hydrophilic emulsifier. This prerinse allows for the removal of excess surface penetrant from the parts prior to emulsification so as to minimize penetrant contamination in the hydrophilic emulsifier bath, thereby extending its life. It is not necessary to prerinse a part if a spray application of emulsifier is used.

8.6.3.2 *Prerinsing Controls*—Effective prerinsing is accomplished by manual, semi-automated, or automated water spray rinsing of the part(s). The water spray pressure shall not exceed 40 psi [275 kPa] when manual or hydro air spray guns are used. When hydro-air pressure spray guns are used, the air pressure shall not exceed 25 psi [172 kPa]. Water free of contaminants that could clog spray nozzles or leave a residue on the part(s) is recommended.

8.6.3.3 *Application of Emulsifier*—The residual surface penetrant on part(s) must be emulsified by immersing the part(s) in an agitated hydrophilic emulsifier bath or by spraying the part(s) with water/emulsifier solutions thereby rendering the remaining residual surface penetrant water-washable for the final rinse station. The emulsification time begins as soon as the emulsifier is applied. The length of time that the emulsifier is allowed to remain on a part and in contact with the penetrant is dependent on the type of emulsifier employed and the surface roughness. The emulsification time should be determined experimentally for each specific application. The surface finish (roughness of the part is a significant factor in determining the emulsification time necessary for an emulsifier. Contact emulsification time should be kept to the least possible time consistent with an acceptable background and shall not exceed two minutes.

8.6.3.4 *Immersion*—For immersion application, parts shall be completely immersed in the emulsifier bath. The hydrophilic emulsifier concentration shall be as recommended by the manufacturer and the bath or part shall be gently agitated by air or mechanically throughout the cycle. The minimum time to obtain an acceptable background shall be used, but the dwell time shall not be more than two minutes unless approved by the contracting parties.

8.6.3.5 *Spray Application*—For spray applications, all part surfaces should be evenly and uniformly sprayed with a water/emulsifier solution to effectively emulsify the residual penetrant on part surfaces to render it water-washable. The concentration of the emulsifier for spray application should be in accordance with the manufacturer's recommendations, but it shall not exceed 5 %. The water spray pressure should be less than 40 psi [275 kpa]. Contact with the emulsifier shall be kept to the minimum time to obtain an acceptable background and shall not exceed two minutes. The water temperature shall be maintained between 50 and 100°F [10 and 38°C].

8.6.3.6 *Post-Rinsing of Hydrophilic Emulsified Penetrants*—Effective post-rinsing of emulsified penetrant from the surface can be accomplished using either manual or automated water spray, water immersion, or combinations thereof. The total rinse time shall not exceed two minutes regardless of the number of rinse methods used.

8.6.3.7 *Immersion Post-Rinsing*—If an agitated immersion rinse is used, the amount of time the part(s) is (are) in the bath shall be the minimum required to remove the emulsified penetrant and shall not exceed two minutes. In addition, the temperature range of the water shall be within 50 and 100°F [10 and 38°C]. Be aware that a touch-up rinse may be necessary after immersion rinse, but the total wash time still shall not exceed two minutes.

8.6.3.8 *Spray Post-Rinsing*—Effective post-rinsing following emulsification can also be accomplished by manual, semi-automatic, or automatic water spray. The water spray pressure shall not exceed 40 psi [275 kPa] when manual or hydro air spray guns are used. When hydro-air pressure spray guns are used, the air pressure shall not exceed 25 psi [172 kPa]. The water temperature shall be between 50 and 100°F [10 and 38°C]. The spray rinse time shall be less than two minutes, unless otherwise specified.

8.6.3.9 *Rinse Effectiveness*—If the emulsification and final rinse steps are not effective, as evidenced by excessive residual surface penetrant after emulsification and rinsing, thoroughly reclean, and completely reprocess the part.

8.6.4 *Removal of Solvent-Removable Penetrant (Method C)*—After the required penetrant dwell time, the excess penetrant is removed by wiping with a dry, clean, lint-free cloth/towel. Then use a clean, lint-free cloth/towel lightly moistened with solvent remover to remove the remaining traces of surface penetrant. Gentle wiping must be used to avoid removing penetrant from any discontinuity. On smooth surfaces, an alternate method of removal can be done by wiping with a clean, dry cloth. Flushing the surface with solvent following the application of the penetrant and prior to developing is prohibited.

8.7 *Drying*—Regardless of the type and method of penetrant used, drying the surface of the part(s) is necessary prior to applying dry or nonaqueous developers or following the application of the aqueous developer. Drying time will vary with the type of drying used and the size, nature, geometry, and number of parts being processed.

8.7.1 *Drying Parameters*—Components shall be air dried at room temperature or in a drying oven. Room temperature drying can be aided by the use of fans. Oven temperatures shall not exceed 160°F [71°C]. Drying time shall only be that necessary to adequately dry the part. Components shall be removed from the oven after drying. Components should not be placed in the oven with pooled water or pooled aqueous solutions/suspensions.

8.8 *Developer Application*—There are various modes of effective application of the various types of developers such as dusting, immersing, flooding or spraying. The developer form, the part size, configuration, and surface roughness will influence the choice of developer application.

8.8.1 *Dry Powder Developer (Form A)*—Dry powder developers shall be applied after the part is dry in such a manner as to ensure complete coverage of the area of interest. Parts can be immersed in a container of dry developer or in a fluid bed of dry developer. They can also be dusted with the powder developer through a hand powder bulb or a conventional or electrostatic powder gun. It is common and effective to apply dry powder in an enclosed dust chamber, which creates an effective and controlled dust cloud. Other means suited to the size and geometry of the specimen may be used, provided the powder is applied evenly over the entire surface being examined. Excess developer powder may be removed by shaking or tapping the part, or by blowing with low-pressure dry, clean, compressed air not exceeding 5 psi [34 kPa]. Dry developers shall not be used with Type II penetrant.

8.8.2 *Aqueous Developers (Forms B and C)*—Water soluble developers (Form B) are prohibited for use with Type 2 penetrants or Type 1, Method A penetrants. Water suspendable developers (Form C) can be used with both Type 1 and Type 2 penetrants. Aqueous developers shall be applied to the part immediately after the excess penetrant has been removed and prior to drying. Aqueous developers shall be prepared and maintained in accordance with the manufacturer's instructions and applied in such a manner as to ensure complete, even, part coverage. Aqueous developers may be applied by spraying, flowing, or immersing the part in a prepared developer bath. Immerse the parts only long enough to coat all of the part surfaces with the developer since indications may leach out if the parts are left in the bath too long. After the parts are removed from the developer bath, allow the parts to drain. Drain all excess developer from recesses and trapped sections to eliminate pooling of developer, which can obscure discontinuities. Dry the parts in accordance with 8.7. The dried developer coating appears as a translucent or white coating on the part.

8.8.3 *Nonaqueous Wet Developers (Forms D and E)*—After the excess penetrant has been removed and the surface has been dried, apply nonaqueous wet developer by spraying in such a manner as to ensure complete part coverage with a thin, even film of developer. The developer shall be applied in a manner appropriate to the type of penetrant being used. For visible dye, the developer must be applied thickly enough to provide a contrasting background. For fluorescent dye, the developer must be applied thinly to produce a translucent covering. Dipping or flooding parts with nonaqueous developers is prohibited, because the solvent action of these types of developers can flush or dissolve the penetrant from within the discontinuities.

NOTE 12—The vapors from the volatile solvent carrier in the developer may be hazardous. Proper ventilation should be provided at all times, but especially when the developer is applied inside a closed area.

8.8.4 *Liquid Film Developers*—Apply by spraying as recommended by the manufacturer. Spray parts in such a manner as to ensure complete part coverage of the area being examined with a thin, even film of developer.

8.8.5 *Developing Time*—The length of time the developer is to remain on the part prior to inspection shall be not less than ten minutes. Developing time begins immediately after the application of dry powder developer or as soon as the wet (aqueous or nonaqueous) developer coating is dry (that is, the water or solvent carrier has evaporated to dryness). The maximum permitted developing times shall be four hours for dry powder developer (Form A), two hours for aqueous developer (Forms B and C), and one hour for nonaqueous developer (Forms D and E).

8.9 *Inspection*—After the applicable development time, perform inspection of the parts under visible or ultraviolet light as appropriate. It may be helpful to observe the bleed out during the development time as an aid in interpreting indications.

8.9.1 *Ultraviolet Light Examination*—Examine parts tested with Type 1 fluorescent penetrant under black light in a darkened area. Ambient light shall not exceed 2 fc [21.5 lx]. The measurement shall be made with a suitable visible light sensor at the inspection surface.

NOTE 13—Because the fluorescent constituents in the penetrant will eventually fade with direct exposure to ultraviolet lights, direct exposure of the part under test to ultraviolet light should be minimized when not removing excess penetrant or evaluating indications.

8.9.1.1 *Black Light Level Control*—Black lights shall provide a minimum light intensity of 1000 µW/cm^2, at a distance of 15 in. [38.1 cm]. The intensity shall be checked daily to ensure the required output (see Guide E2297 for more information). Reflectors and filters shall also be checked daily for cleanliness and integrity. Cracked or broken ultraviolet filters shall be replaced immediately. Since a drop in line voltage can cause decreased black light output with consequent inconsistent performance, a constant-voltage transformer should be used when there is evidence of voltage fluctuation.

NOTE 14—Certain high-intensity black lights may emit unacceptable amounts of visible light, which can cause fluorescent indications to disappear. Care should be taken to only use bulbs suitable for fluorescent penetrant testing purposes.

8.9.1.2 *Black Light Warm-Up*—Unless otherwise specified by the manufacturer, allow the black light to warm up for a minimum of five minutes prior to use or measurement of its intensity.

8.9.1.3 *Visual Adaptation*—Personnel examining parts after penetrant processing shall be in the darkened area for at least one minute before examining parts. Longer times may be necessary under some circumstances. Photochromic or tinted lenses shall not be worn during the processing and examination of parts.

8.9.2 *Visible Light Examination*—Inspect parts tested with Type 2 visible penetrant under either natural or artificial visible light. Proper illumination is required to ensure adequate sensitivity of the examination. A minimum light intensity at the examination surface of 100 fc [1076 lx] is required (see Guide E2297 for more information).

8.9.3 *Housekeeping*—Keep the examination area free of interfering debris, including fluorescent residues and objects.

8.9.4 *Indication Verification*—For Type 1 inspections only, it is common practice to verify indications by wiping the indication with a solvent-dampened swab or brush, allowing the area to dry, and redeveloping the area. Redevelopment time shall be a minimum of ten minutes, except nonaqueous redevelopment time should be a minimum of three minutes. If the indication does not reappear, the original indication may be considered false. This procedure may be performed up to two times for any given original indication.

8.9.5 *Evaluation*—All indications found during inspection shall be evaluated in accordance with acceptance criteria as specified. Reference Photographs of indications are noted in E433).

8.10 *Post Cleaning*—Post cleaning is necessary when residual penetrant or developer could interfere with subsequent processing or with service requirements. It is particularly important where residual penetrant testing materials might combine with other factors in service to produce corrosion and prior to vapor degreasing or heat treating the part as these processes can bake the developer onto the part. A suitable technique, such as a simple water rinse, water spray, machine wash, solvent soak, or ultrasonic cleaning may be employed (see Annex A1 for further information on post cleaning). It is recommended that if developer removal is necessary, it should be carried out as promptly as possible after examination so that the developer does not adhere to the part.

9. Special Requirements

9.1 *Impurities:*

9.1.1 When using penetrant materials on austenitic stainless steels, titanium, nickel-base or other high-temperature alloys, the need to restrict certain impurities such as sulfur, halogens and alkali metals must be considered. These impurities may cause embrittlement or corrosion, particularly at elevated temperatures. Any such evaluation shall also include consideration of the form in which the impurities are present. Some penetrant materials contain significant amounts of these impurities in the form of volatile organic solvents that normally evaporate quickly and usually do not cause problems. Other materials may contain impurities, which are not volatile and may react with the part, particularly in the presence of moisture or elevated temperatures.

9.1.2 Because volatile solvents leave the surface quickly without reaction under normal examination procedures, penetrant materials are normally subjected to an evaporation procedure to remove the solvents before the materials are analyzed for impurities. The residue from this procedure is then analyzed in accordance with Test Method D1552 or Test Method D129 decomposition followed by Test Method E516, Method B (Turbidimetric Method) for sulfur. The residue may also be analyzed by Test Method D808 or Annex A2 on Methods for Measuring Total Chlorine Content in Combustible Liquid Penetrant Materials (for halogens other than fluorine) and Annex A3 on Method for Measuring Total Fluorine Content in Combustible Liquid Penetration Materials (for fluorine). An alternative procedure, Annex A4 on Determination of Anions by Ion Chromatography, provides a single instrumental technique for rapid sequential measurement of common anions such as chloride, fluoride, and sulfate. Alkali metals in the residue are determined by flame photometry, atomic absorption spectrophotometry, or ion chromatography (see ASTM D4327).

NOTE 15—Some current standards require impurity levels of sulfur and halogens to not exceed 1 % of any one suspect element. This level, however, may be unacceptable for some applications, so the actual maximum acceptable impurity level must be decided between supplier and user on a case by case basis.

9.2 *Elevated-Temperature Testing*—Where penetrant testing is performed on parts that must be maintained at elevated temperature during examination, special penetrant materials and processing techniques may be required. Such examination requires qualification in accordance with 10.2 and the manufacturer's recommendations shall be observed.

10. Qualification and Requalification

10.1 *Personnel Qualification*—When required by the customer, all penetrant testing personnel shall be qualified/certified in accordance with a written procedure conforming to the applicable edition of recommended Practice SNT-TC-1A, ANSI/ASNT CP-189, NAS-410, or MIL-STD-410.

10.2 *Procedure Qualification*—Qualification of procedures using times, conditions, or materials differing from those specified in this general practice or for new materials may be performed by any of several methods and should be agreed upon by the contracting parties. A test piece containing one or more discontinuities of the smallest relevant size is generally used. When agreed upon by the contracting parties, the test piece may contain real or simulated discontinuities, providing it displays the characteristics of the discontinuities encountered in product examination.

10.2.1 Requalification of the procedure to be used may be required when a change is made to the procedure or when material substitution is made.

10.3 *Nondestructive Testing Agency Qualification*—If a nondestructive testing agency as described in Practice E543 is used to perform the examination, the agency should meet the requirements of Practice E543.

10.4 *Requalification* may be required when a change or substitution is made in the type of penetrant materials or in the procedure (see 10.2).

11. Keywords

11.1 fluorescent liquid penetrant testing; hydrophilic emulsification; lipophilic emulsification; liquid penetrant testing; nondestructive testing; solvent removable; visible liquid penetrant testing; water-washable; post-emulsified; black light; ultraviolet light; visible light

ANNEXES

(Mandatory Information)

A1. CLEANING OF PARTS AND MATERIALS

A1.1 Choice of Cleaning Method

A1.1.1 The choice of a suitable cleaning method is based on such factors as: (*1*) type of contaminant to be removed since no one method removes all contaminants equally well; (*2*) effect of the cleaning method on the parts; (*3*) practicality of the cleaning method for the part (for example, a large part cannot be put into a small degreaser or ultrasonic cleaner); and (*4*) specific cleaning requirements of the purchaser. The following cleaning methods are recommended:

A1.1.1.1 *Detergent Cleaning*—Detergent cleaners are nonflammable water-soluble compounds containing specially selected surfactants for wetting, penetrating, emulsifying, and saponifying various types of soils, such as grease and oily films, cutting and machining fluids, and unpigmented drawing compounds, etc. Detergent cleaners may be alkaline, neutral, or acidic in nature, but must be noncorrosive to the item being inspected. The cleaning properties of detergent solutions facilitate complete removal of soils and contamination from the surface and void areas, thus preparing them to absorb the penetrant. Cleaning time should be as recommended by the manufacturer of the cleaning compound.

A1.1.1.2 *Solvent Cleaning*—There are a variety of solvent cleaners that can be effectively utilized to dissolve such soils as grease and oily films, waxes and sealants, paints, and in general, organic matter. These solvents should be residue-free, especially when used as a hand-wipe solvent or as a dip-tank degreasing solvent. Solvent cleaners are not recommended for the removal of rust and scale, welding flux and spatter, and in general, inorganic soils. Some cleaning solvents are flammable and can be toxic. Observe all manufacturers' instructions and precautionary notes.

A1.1.1.3 *Vapor Degreasing*—Vapor degreasing is a preferred method of removing oil or grease-type soils from the surface of parts and from open discontinuities. It will not remove inorganic-type soils (dirt, corrosion, salts, etc.), and may not remove resinous soils (plastic coatings, varnish, paint, etc.). Because of the short contact time, degreasing may not completely clean out deep discontinuities and a subsequent solvent soak is recommended.

A1.1.1.4 *Alkaline Cleaning:*

(a) Alkaline cleaners are nonflammable water solutions containing specially selected detergents for wetting, penetrating, emulsifying, and saponifying various types of soils. Hot alkaline solutions are also used for rust removal and descaling to remove oxide scale which can mask surface discontinuities. Alkaline cleaner compounds must be used in accordance with the manufacturers' recommendations. Parts cleaned by the alkaline cleaning process must be rinsed completely free of cleaner and thoroughly dried prior to the penetrant testing process (part temperature at the time of penetrant application shall not exceed 125°F [52°C].

(b) Steam cleaning is a modification of the hot-tank alkaline cleaning method, which can be used for preparation of large, unwieldy parts. It will remove inorganic soils and many organic soils from the surface of parts, but may not reach to the bottom of deep discontinuities, and a subsequent solvent soak is recommended.

A1.1.1.5 *Ultrasonic Cleaning*—This method adds ultrasonic agitation to solvent or detergent cleaning to improve cleaning efficiency and decrease cleaning time. It should be used with water and detergent if the soil to be removed is inorganic (rust, dirt, salts, corrosion products, etc.), and with organic solvent if the soil to be removed is organic (grease and oily films, etc.).

After ultrasonic cleaning, parts must be rinsed completely free of cleaner, thoroughly dried, and cooled to at least 125°F [52°C], before application of penetrant.

A1.1.1.6 *Paint Removal*—Paint films can be effectively removed by bond release solvent paint remover or disintegrating-type hot-tank alkaline paint strippers. In most cases, the paint film must be completely removed to expose the surface of the metal. Solvent-type paint removers can be of the high-viscosity thickened type for spray or brush application or can be of low viscosity two-layer type for dip-tank application. Both types of solvent paint removers are generally used at ambient temperatures, as received. Hot-tank alkaline strippers should be used in accordance with the manufacturer's instructions. After paint removal, the parts must be thoroughly rinsed to remove all contamination from the void openings, thoroughly dried, and cooled to at least 125°F [52°C] before application of penetrant.

A1.1.1.7 *Mechanical Cleaning and Surface Conditioning*—Metal-removing processes such as filing, buffing, scraping, mechanical milling, drilling, reaming, grinding, liquid honing, sanding, lathe cutting, tumble or vibratory deburring, and abrasive blasting, including abrasives such as glass beads, sand, aluminum oxide, ligno-cellulose pellets, metallic shot, etc., are often used to remove such soils as carbon, rust and scale, and foundry adhering sands, as well as to deburr or produce a desired cosmetic effect on the part. *These processes may decrease the effectiveness of the penetrant testing by smearing or peening over metal surfaces and filling discontinuities open to the surface, especially for soft metals such as aluminum, titanium, magnesium, and beryllium alloy.*

A1.1.1.8 *Acid Etching*—Inhibited acid solutions (pickling solutions) are routinely used for descaling part surfaces. Descaling is necessary to remove oxide scale, which can mask surface discontinuities and prevent penetrant from entering. Acid solutions/etchants are also used routinely to remove smeared metal that peens over surface discontinuities. Such etchants should be used in accordance with the manufacturers' recommendations.

NOTE A1.1—Etched parts and materials should be rinsed completely free of etchants, the surface neutralized and thoroughly dried by heat prior to application of penetrants. Acids and chromates can adversely affect the fluorescence of fluorescent materials.

NOTE A1.2—Whenever there is a possibility of hydrogen embrittlement as a result of acid solution/etching, the part should be baked at a suitable temperature for an appropriate time to remove the hydrogen before further processing. After baking, the part shall be cooled to a temperature below 125°F [52°C] before applying penetrants.

A1.1.1.9 *Air Firing of Ceramics*—Heating of a ceramic part in a clean, oxidizing atmosphere is an effective way of removing moisture or light organic soil or both. The maximum temperature that will not cause degradation of the properties of the ceramic should be used.

A1.2 Post Cleaning

A1.2.1 *Removal of Developer*—Dry powder developer can be effectively removed with an air blow-off (free of oil) or it can be removed with water rinsing. Wet developer coatings can be removed effectively by water rinsing or water rinsing with detergent either by hand or with a mechanical assist (scrub brushing, machine washing, etc.). The soluble developer coatings simply dissolve off of the part with a water rinse.

A1.2.2 Residual penetrant may be removed through solvent action. Solvent soaking (15 min minimum), and ultrasonic solvent cleaning (3 min minimum) techniques are recommended. In some cases, it is desirable to vapor degrease, then follow with a solvent soak. The actual time required in the vapor degreaser and solvent soak will depend on the nature of the part and should be determined experimentally.

A2. METHODS FOR MEASURING TOTAL CHLORINE CONTENT IN COMBUSTIBLE LIQUID PENETRANT MATERIALS

A2.1 Scope and Application

A2.1.1 These methods cover the determination of chlorine in combustible liquid penetrant materials, liquid or solid. Its range of applicability is 0.001 to 5 % using either of the alternative titrimetric procedures. The procedures assume that bromine or iodine will not be present. If these elements are present, they will be detected and reported as chlorine. The full amount of these elements will not be reported. Chromate interferes with the procedures, causing low or nonexistent end points. The method is applicable only to materials that are totally combustible.

A2.2 Summary of Methods

A2.2.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (see A2.2.1.1). The chlorine compounds thus liberated are absorbed in a sodium carbonate solution and the amount of chloride present is determined titrimetrically either against silver nitrate with the end point detected potentiometrically (Method A) or coulometrically with the end point detected by current flow increase (Method B).

A2.2.1.1 *Safety*—Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least ½ in. [12.7 mm] thick, or equivalent protection be provided against unforeseeable contingencies.

A2.3 Apparatus

A2.3.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

A2.3.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside and weighing 10 to 11 g, opaque fused silica, wide-form with an outside diameter of 29 mm at the top, a height of 19 mm, and a 5-mL capacity (Note 1), or nickel (Kawin capsule form), top diameter of 28 mm, 15 mm in height, and 5-mL capacity.

NOTE A2.1—Fused silica crucibles are much more economical and longer-lasting than platinum. After each use, they should be scrubbed out with fine, wet emery cloth, heated to dull red heat over a burner, soaked in hot water for 1 h, then dried and stored in a desiccator before reuse.

A2.3.3 *Firing Wire,* platinum, approximately No. 26 B & S gage.

A2.3.4 *Ignition Circuit* (Note A2.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A2.2—The switch in the ignition circuit should be of a type that remains open, except when held in closed position by the operator.

A2.3.5 *Nylon Sewing Thread,* or *Cotton Wicking*, white.

A2.4 Purity of Reagents

A2.4.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

A2.4.2 Unless otherwise indicated, references to water shall be understood to mean referee grade reagent water conforming to Specification D1193.

A2.5 Sample Preparation

A2.5.1 *Penetrants, Developers, Emulsifiers, Magnetic Oils:*

A2.5.1.1 Weigh 50 g of test material into a 150-mm petri dish.

A2.5.1.2 Place the 150-mm petri dish into a 194°F [90°C] to 212°F [100°C] oven for 60 minutes.

A2.5.1.3 Allow the test material to cool to room temperature.

A2.5.2 *Solvent Cleaners:*

A2.5.2.1 Take the tare weight of an aluminum dish.

A2.5.2.2 Weigh 100 g of the cleaner into the aluminum dish.

A2.5.2.3 Place the aluminum dish on a hot plate in a fume hood.

A2.5.2.4 Let the material evaporate until the dish is nearly dry.

A2.5.2.5 Place the dish into a preheated oven from 194°F [90°C] to 212°F [100°C] for 10 minutes.

A2.5.2.6 Take the dish out of the oven and allow to cool.

A2.5.2.7 Reweigh the dish and record weight.

NOTE A2.3—*For Cleaners*—If the residue is less than 50 ppm, report the residue weight. If the weight is greater than 50 ppm, proceed with the bomb procedure.

A2.6 Decomposition

A2.6.1 *Reagents and Materials:*

A2.6.1.1 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 40 atm [4.05 MPa].

A2.6.1.2 *Sodium Carbonate Solution (50 g Na_2CO_3/L)*—Dissolve 50 g of anhydrous Na_2CO_3 or 58.5 g of $Na_2CO_3{\cdot}{}_2O$) or 135 g of $Na_2CO_3{\cdot}10H_2O$ in water and dilute to 1 L.

A2.6.1.3 *White Oil,* refined.

A2.6.2 *Procedure:*

A2.6.2.1 *Preparation of Bomb and Sample*—Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 5 mL of Na_2CO_3 solution in the bomb (Note A2.4), place the cover on the bomb and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. Use of a sample weight containing over 20 mg of chlorine may cause corrosion of the bomb. The sample weight should not exceed 0.4 g if the expected chlorine content is 2.5 % or above. If the sample is solid, not more than 0.2 g should be used. Use 0.8 g of white oil with solid samples. If white oil will be used (Note A2.5), add it to the sample cup by means of a dropper at this time (see Note A2.6 and Note A2.7).

NOTE A2.4—After repeated use of the bomb for chlorine determination, a film may be noticed on the inner surface. This dullness should be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside surface with Grit No. 2/0 or equivalent paper coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before using the bomb, it should be washed with soap and water to remove oil or paste left from the polishing operation. Bombs with porous or pitted surfaces should never be used because of the tendency to retain chlorine from sample to sample. It is recommended to not use more than 1 g total of sample and white oil or other chlorine-free combustible material.

NOTE A2.5—If the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil.

NOTE A2.6—The practice of running alternately samples high and low in chlorine content should be avoided whenever possible. It is difficult to rinse the last traces of chlorine from the walls of the bomb and the tendency for residual chlorine to carry over from sample to sample has been observed in a number of laboratories. When a sample high in chlorine has preceded one low in chlorine content, the test on the low-chlorine sample should be repeated and one or both of the low values thus obtained should be considered suspect if they do not agree within the limits of repeatability of this method.

A2.6.2.2 *Addition of Oxygen*—Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (see Note A2.7) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A2.1.

NOTE A2.7—It is recommended to not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A2.6.2.3 *Combustion*—Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least ten minutes. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use (Note A2.4).

A2.7 Analysis, Method A, Potentiometric Titration Procedure

A2.7.1 *Apparatus:*

A2.7.1.1 *Silver Billet Electrode.*

A2.7.1.2 *Glass Electrode,* pH measurement type.

A2.7.1.3 *Buret,* 25-mL capacity, 0.05-mL graduations.

A2.7.1.4 *Millivolt Meter,* or expanded scale pH meter capable of measuring 0 to 220 mV.

NOTE A2.8—An automatic titrator is highly recommended in place of items A2.7.1.3 and A2.7.1.4. Repeatability and sensitivity of the method are much enhanced by the automatic equipment while much tedious effort is avoided.

A2.7.2 *Reagents and Materials:*

A2.7.2.1 *Acetone,* chlorine-free.

A2.7.2.2 *Methanol,* chlorine-free.

A2.7.2.3 *Silver Nitrate Solution (0.0282 N)*—Dissolve 4.7910 ± 0.0005 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

A2.7.2.4 *Sodium Chloride Solution (0.0282 N)*—Dry a few grams of sodium chloride (NaCl) for 2 h at 130 to 150°C, weigh out 1.6480 ± 0.0005 g of the dried NaCl, dissolve in water, and dilute to 1 L.

A2.7.2.5 *Sulfuric Acid (1 + 2)*—Mix 1 volume of concentrated sulfuric acid (H_2SO_4, sp. gr 1.84) with 2 volumes of water.

TABLE A2.1 Gauge Pressures

Capacity of Bomb, mL	Gauge Pressure, atm [MPa]	
	min[A]	max
300 to 350	38 [3.85]	40 [4.05]
350 to 400	35 [3.55]	37 [3.75]
400 to 450	30 [3.04]	32 [3.24]
450 to 500	27 [2.74]	29 [2.94]

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

A2.7.3 *Collection of Chlorine Solution*—Remove the sample cup with clean forceps and place in a 400-mL beaker. Wash down the walls of the bomb shell with a fine stream of methanol from a wash bottle, and pour the washings into the beaker. Rinse any residue into the beaker. Next, rinse the bomb cover and terminals into the beaker. Finally, rinse both inside and outside of the sample crucible into the beaker. Washings should equal but not exceed 100 mL. Add methanol to make 100 mL.

A2.7.4 *Determination of Chlorine*—Add 5 mL of H_2SO_4 (1:2) to acidify the solution (solution should be acid to litmus and clear of white Na_2CO_3 precipitate). Add 100 mL of acetone. Place the electrodes in the solution, start the stirrer (if mechanical stirrer is to be used), and begin titration. If titration is manual, set the pH meter on the expanded millivolt scale and note the reading. Add exactly 0.1 mL of $AgNO_3$ solution from the buret. Allow a few seconds stirring; then record the new millivolt reading. Subtract the second reading from the first. Continue the titration, noting each amount of $AgNO_3$ solution and the amount of difference between the present reading and the last reading. Continue adding 0.1-mL increments, making readings and determining differences between readings until a maximum difference between readings is obtained. The total amount of $AgNO_3$ solution required to produce this maximum differential is the end point. Automatic titrators continuously stir the sample, add titrant, measure the potential difference, calculate the differential, and plot the differential on a chart. The maximum differential is taken as the end point.

NOTE A2.9—For maximum sensitivity, 0.00282 *N* $AgNO_3$ solution may be used with the automatic titrator. This dilute reagent should not be used with large samples or where chlorine content may be over 0.1 % since these tests will cause end points of 10 mL or higher. The large amount of water used in such titrations reduces the differential between readings, making the end point very difficult to detect. For chlorine contents over 1 % in samples of 0.8 g or larger, 0.282 *N* $AgNO_3$ solution will be required to avoid exceeding the 10-mL water dilution limit.

A2.7.5 *Blank*—Make blank determinations with the amount of white oil used but omitting the sample. (Liquid samples normally require only 0.15 to 0.25 g of white oil while solids require 0.7 to 0.8 g.) Follow normal procedure, making two or three test runs to be sure the results are within the limits of repeatability for the test. Repeat this blank procedure whenever new batches of reagents or white oil are used. The purpose of the blank run is to measure the chlorine in the white oil, the reagents, and that introduced by contamination.

A2.7.6 *Standardization*—Silver nitrate solutions are not permanently stable, so the true activity should be checked when the solution is first made up and then periodically during the life of the solution. This is done by titration of a known NaCl solution as follows: Prepare a mixture of the amounts of the chemicals (Na_2CO_3 solution, H_2SO_4 solution, acetone, and methanol) specified for the test. Pipet in 5.0 mL of 0.0282-*N* NaCl solution and titrate to the end point. Prepare and titrate a similar mixture of all the chemicals except the NaCl solution, thus obtaining a reagent blank reading. Calculate the normality of the $AgNO_3$ solution as follows:

$$N_{AgNO3} = \frac{5.0 \times N_{NaCl}}{V_A - V_B} \quad \text{(A2.1)}$$

where:

N_{AgNO3} = normality of the $AgNO_3$ solution,
N_{NaCl} = normality of the NaCl solution,
V_A = millilitres of $AgNO_3$ solution used for the titration including the NaCl solution, and
V_B = millilitres of $AgNO_3$ solution used for the titration of the reagents only.

A2.7.7 *Calculation*—Calculate the chlorine content of the sample as follows:

$$\text{Chlorine, weight \%} = \frac{(V_S - V_B) \times N \times 3.545}{W} \quad (A2.2)$$

where:

V_S = millilitres of $AgNO_3$ solution used by the sample,
V_B = millilitres of $AgNO_3$ solution used by the blank,
N = normality of the $AgNO_3$ solution, and
W = grams of sample used.

A2.7.8 *Precision and Accuracy:*

A2.7.8.1 The following criteria should be used for judging the acceptability of results:

A2.7.8.1.1 *Repeatability*—Results by the same analyst should not be considered suspect unless they differ by more than 0.006 % or 10.5 % of the value determined, whichever is higher.

A2.7.8.1.2 *Reproducibility*—Results by different laboratories should not be considered suspect unless they differ by more than 0.013 % or 21.3 % of the value detected, whichever is higher.

A2.7.8.1.3 *Accuracy*—The average recovery of the method is 86 % to 89 % of the actual amount present.

A2.8 Analysis, Method B, Coulometric Titration

A2.8.1 *Apparatus:*

A2.8.1.1 *Coulometric Chloride Titrator.*

A2.8.1.2 *Beakers,* two, 100-mL, or glazed crucibles (preferably with 1½ in.-outside diameter bottom).

A2.8.1.3 *Refrigerator.*

A2.8.2 *Reagents:*

A2.8.2.1 *Acetic Acid, Glacial.*

A2.8.2.2 *Dry Gelatin Mixture.*

A2.8.2.3 *Nitric Acid.*

A2.8.2.4 *Sodium Chloride Solution*—100 meq C/1. Dry a quantity of NaCl for 2 h at 130 to 150°C. Weigh out 5.8440 ± 0.0005 g of dried NaCl in a closed container, dissolve in water, and dilute to 1 L.

A2.8.3 *Reagent Preparation:*

NOTE A2.10—The normal reagent preparation process has been slightly changed, due to the interference from the 50 mL of water required to wash the bomb. This modified process eliminates the interference and does not alter the quality of the titration.

A2.8.3.1 *Gelatin Solution*—A typical preparation is: Add approximately 1 L of hot distilled or deionized water to the 6.2 g of dry gelatin mixture contained in one vial supplied by the equipment manufacturer. Gently heat with continuous mixing until the gelatin is completely dissolved.

A2.8.3.2 Divide into aliquots each sufficient for one day's analyses. (Thirty millilitres is enough for approximately eleven titrations.) Keep the remainder in a refrigerator, but do not freeze. The solution will keep for about six months in the refrigerator. When ready to use, immerse the day's aliquot in hot water to liquefy the gelatin.

A2.8.3.3 *Glacial Acetic Acid-Nitric Acid Solution*—A typical ratio is 12.5 to 1 (12.5 parts CH_3COOH to 1 part HNO_3).

A2.8.3.4 Mix enough gelatin solution and of acetic acid-nitric acid mixture for one titration. (A typical mixture is 2.5 mL of gelatin solution and 5.4 mL of acetic-nitric acid mixture.)

NOTE A2.11—The solution may be premixed in a larger quantity for convenience, but may not be useable after 24 h.

A2.8.3.5 Run at least three blank values and take an average according to the operating manual of the titrator. Determine separate blanks for both five drops of mineral oil and 20 drops of mineral oil.

A2.8.4 *Titration:*

A2.8.4.1 Weigh to the nearest 0.1 g and record the weight of the 100-mL beaker.

A2.8.4.2 Remove the sample crucible from the cover assembly support ring using a clean forceps, and, using a wash bottle, rinse both the inside and the outside with water into the 100-mL beaker.

A2.8.4.3 Empty the bomb shell into the 100-mL beaker. Wash down the sides of the bomb shell with water, using a wash bottle.

A2.8.4.4 Remove the cover assembly from the cover assembly support, and, using the wash bottle, rinse the under side, the platinum wire, and the terminals into the same 100-mL beaker. The total amount of washings should be 50 ± 1 g.

A2.8.4.5 Add specified amounts of gelatin mixture and acetic acid-nitric acid mixture, or gelatin mix-acetic acid-nitric acid mixture, if this was premixed, into the 100-mL beaker that contains the 50 g of washings including the decomposed sample.

A2.8.4.6 Titrate using a coulometric titrimeter, according to operating manual procedure.

A2.8.5 *Calculations*—Calculate the chloride ion concentration in the sample as follows:

$$\text{Chlorine, weight \%} = \frac{(P - B) \times M}{W} \quad (A2.3)$$

where:

P = counter reading obtained with the sample,
B = average counter reading obtained with average of the three blank readings,
M = standardization constant. This is dependent on the instrument range setting in use and the reading obtained with a known amount of the 100 meq of Cl per litre of solution, and
W = weight of sample used, g.

A2.8.6 *Precision and Accuracy:*

A2.8.6.1 Duplicate results by the same operator can be expected to exhibit the following relative standard deviations:

Approximate % Chlorine	RSD, %
1.0 and above	0.10
0.1	2.5
0.003	5.9

A2.8.6.2 The method can be expected to report values that vary from the true value by the following amounts:

0.1 % chlorine and above	±2%
0.001 to 0.01 % chlorine	±9%.

A2.8.6.3 If bromine is present, 36.5 % of the true amount will be reported. If iodine is present, 20.7 % of the true amount will be reported. Fluorine will not be detected.

A3. METHOD FOR MEASURING TOTAL FLUORINE CONTENT IN COMBUSTIBLE LIQUID PENETRANT MATERIALS

A3.1 Scope and Application

A3.1.1 This method covers the determination of fluorine in combustible liquid penetrant materials, liquid or solid, that do not contain appreciable amounts of interfering elements, or have any insoluble residue after combustion. Its range of applicability is 1 to 200 000 ppm.

A3.1.2 The measure of the fluorine content employs the fluoride selective ion electrode.

A3.2 Summary of Method

A3.2.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (see A3.2.1.1). The fluorine compounds thus liberated are absorbed in a sodium citrate solution and the amount of fluorine present is determined potentiometrically through the use of a fluoride selective ion electrode.

A3.2.1.1 *Safety*—Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least ½ in. [12.7 mm] thick, or equivalent protection be provided against unforeseeable contingencies.

A3.3 Interferences

A3.3.1 Silicon, calcium, aluminum, magnesium, and other metals forming precipitates with fluoride ion will interfere if they are present in sufficient concentration to exceed the solubility of their respective fluorides. Insoluble residue after combustion will entrain fluorine even if otherwise soluble.

A3.4 Sample Preparation

A3.4.1 *Penetrants, Developers, Emulsifiers, Magnetic Oils:*

A3.4.1.1 Weigh 50 g of test material into a 150-mm petri dish.

A3.4.1.2 Place the 150-mm petri dish into a 194°F [90°C] to 212°F [100°C] oven for 60 minutes.

A3.4.1.3 Allow the test material to cool to room temperature.

A3.4.2 *Solvent Cleaners:*

A3.4.2.1 Take the tare weight of an aluminum dish.

A3.4.2.2 Weigh 100 g of the cleaner into the aluminum dish.

A3.4.2.3 Place the aluminum dish on a hot plate in a fume hood.

A3.4.2.4 Let the material evaporate until the dish is nearly dry.

A3.4.2.5 Place the dish into a preheated oven from 194°F [90°C] to 212°F [100°C] for 10 minutes.

A3.4.2.6 Take the dish out of the oven and allow to cool.

A3.4.2.7 Reweigh the dish and record weight.

NOTE A3.1—*For Cleaners*—If the residue is less than 50 ppm, report the residue weight. If the weight is greater than 50 ppm, proceed with the bomb procedure.

A3.5 Apparatus

A3.5.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the fluorine content of the liquid in the bomb.

A3.5.2 *Sample Cup,* nickel, 20 mm in outside diameter at the bottom, 28 mm in outside diameter at the top, and 16 mm in height; or platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height, and weighing 10 to 11 g.

A3.5.3 *Firing Wire,* platinum, approximately No. 26 B & S gage.

A3.5.4 *Ignition Circuit* (Note A3.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A3.2—**Caution:** The switch in the ignition circuit should be of a type that remains open, except when held in closed position by the operator.

A3.5.5 *Nylon Sewing Thread,* or *Cotton Wicking*, white.

A3.5.6 *Funnel,* polypropylene (Note A3.3).

A3.5.7 *Volumetric Flask,* polypropylene, 100-mL (Note A3.3).

A3.5.8 *Beaker,* polypropylene, 150-mL (Note A3.3).

A3.5.9 *Pipet,* 100-μL, Eppendorf-type (Note A3.3).

A3.5.10 *Magnetic Stirrer* and TFE-coated magnetic stirring bar.

A3.5.11 *Fluoride Specific Ion Electrode* and suitable reference electrode.

A3.5.12 *Millivolt Meter* capable of measuring to 0.1 mV.

NOTE A3.3—Glassware should never be used to handle a fluoride solution as it will remove fluoride ions from solution or on subsequent use carry fluoride ion from a concentrated solution to one more dilute.

A3.6 Reagents

A3.6.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[9] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

A3.6.2 *Purity of Water*—Unless otherwise indicated, all references to water shall be understood to mean Type I reagent water conforming to Specification D1193.

A3.6.3 *Fluoride Solution, Stock (2000 ppm)*—Dissolve 4.4200 ± 0.0005 g of predried (at 130 to 150°C for 1 h, then cooled in a desiccator) sodium fluoride in distilled water and dilute to 1 L.

A3.6.4 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 40 atm [4.05 MPa].

A3.6.5 *Sodium Citrate Solution*—Dissolve 27 g of sodium citrate dihydrate in water and dilute to 1 L.

A3.6.6 *Sodium Hydroxide Solution (5 N)*—Dissolve 200 g of sodium hydroxide (NaOH) pellets in water and dilute to 1 L; store in a polyethylene container.

A3.6.7 *Wash Solution (Modified TISAB, Total Ionic Strength Adjustment Buffer)*—To 300 mL of distilled water, add 32 mL of glacial acetic acid, 6.6 g of sodium citrate dihydrate, and 32.15 g of sodium chloride. Stir to dissolve and then adjust the pH to 5.3 using 5 *N* NaOH solution. Cool and dilute to 1 L.

A3.6.8 *White Oil,* refined.

A3.7 Decomposition Procedure

A3.7.1 *Preparation of Bomb and Sample*—Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 10 mL of sodium citrate solution in the bomb, place the cover on the bomb, and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. The sample weight used should not exceed 1 g. If the sample is a solid, add a few drops of white oil at this time to ensure ignition of the sample.

NOTE A3.4—Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this it is recommended that for samples containing over 2 % chlorine, the sample weight be based on the following table:

Chlorine Content, %	Sample weight, g	White Oil weight, g
2 to 5	0.4	0.4
5 to 10	0.2	0.6
10 to 20	0.1	0.7
20 to 50	0.05	0.7

Do not use more than 1 g total of sample and white oil or other fluorine-free combustible material.

A3.7.2 *Addition of Oxygen*—Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (see Note A3.5) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A3.1.

NOTE A3.5—**Caution:** It is recommended to not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A3.7.3 *Combustion*—Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use.

A3.7.4 *Collection of Fluorine Solution*—Remove the sample cup with clean forceps and rinse with wash solution into a 100-mL volumetric flask. Rinse the walls of the bomb shell with a fine stream of wash solution from a wash bottle, and add the washings to the flask. Next, rinse the bomb cover and terminals into the volumetric flask. Finally, add wash solution to bring the contents of the flask to the line.

A3.8 Procedure

A3.8.1 Ascertain the slope (millivolts per ten-fold change in concentration) of the electrode as described by the manufacturer.

A3.8.2 Obtain a blank solution by performing the procedure without a sample.

A3.8.3 Immerse the fluoride and reference electrodes in solutions and obtain the equilibrium reading to 0.1 mV. (The condition of the electrode determines the length of time

TABLE A3.1 Gauge Pressures

Capacity of Bomb, mL	Gauge Pressure atm (MPa)	
	min[A]	max
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

necessary to reach equilibrium. This may be as little as 5 min or as much as 20 min.)

A3.8.4 Add 100 µL of stock fluoride solution and obtain the reading after the same length of time necessary for A3.8.3.

A3.9 Calculation

A3.9.1 Calculate the fluorine content of the sample as follows:

$$\text{Fluorine, ppm} = \frac{\left[\dfrac{2 \times 10^{-4}}{10\Delta E_1/S - 1} - \dfrac{2 \times 10^{-4}}{10\Delta E_2/S - 1}\right]}{W} \times 10^6 \qquad (A3.1)$$

where:

ΔE_1 = millivolt change in sample solution on addition of 100 µL of stock fluoride solution,
ΔE_2 = millivolt change in blank solution on addition of 100 µL of the stock fluoride solution,
S = slope of fluoride electrode as determined in A3.8.1, and
W = grams of sample.

A3.10 Precision and Bias

A3.10.1 *Repeatability*—The results of two determinations by the same analyst should not be considered suspect unless they differ by more than 1.1 ppm (0.00011 %) or 8.0 % of the amount detected, whichever is greater.

A3.10.2 *Reproducibility*—The results of two determinations by different laboratories should not be considered suspect unless they differ by 6.7 ppm or 129.0 % of the amount detected, whichever is greater.

A3.10.3 *Bias*—The average recovery of the method is 62 to 64 % of the amount actually present although 83 to 85 % recoveries can be expected with proper technique.

A4. DETERMINATION OF ANIONS BY ION CHROMATOGRAPHY WITH CONDUCTIVITY MEASUREMENT

A4.1 Scope and Application

A4.1.1 This method is condensed from ASTM procedures and APHA Method 429 and optimized for the analysis of detrimental substances in organic based materials. It provides a single instrumental technique for rapid, sequential measurement of common anions such as bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulfate.

A4.2 Summary of Method

A4.2.1 The material must be put in the form of an aqueous solution before analysis can be attempted. The sample is oxidized by combustion in a bomb containing oxygen under pressure. The products liberated are absorbed in the eluant present in the bomb at the time of ignition. This solution is washed from the bomb, filtered, and diluted to a known volume.

A4.2.1.1 A filtered aliquot of sample is injected into a stream of carbonate-bicarbonate eluant and passed through a series of ion exchangers. The anions of interest are separated on the basis of their relative affinities for a low capacity, strongly basic anion exchanger (guard and separator column). The separated anions are directed onto a strongly acidic cation exchanger (suppressor column) where they are converted to their highly conductive acid form and the carbonate-bicarbonate eluant is converted to weakly conductive carbonic acid. The separated anions in their acid form are measured by conductivity. They are identified on the basis of retention time as compared to standards. Quantitation is by measurement of peak area or peak height. Blanks are prepared and analyzed in a similar fashion.

A4.2.2 *Interferences*—Any substance that has a retention time coinciding with that of any anion to be determined will interfere. For example, relatively high concentrations of low-molecular-weight organic acids interfere with the determination of chloride and fluoride. A high concentration of any one ion also interferes with the resolution of others. Sample dilution overcomes many interferences. To resolve uncertainties of identification or quantitation use the method of known additions. Spurious peaks may result from contaminants in reagent water, glassware, or sample processing apparatus. Because small sample volumes are used, scrupulously avoid contamination.

A4.2.3 *Minimum Detectable Concentration*—The minimum detectable concentration of an anion is a function of sample size and conductivity scale used. Generally, minimum detectable concentrations are in the range of 0.05 mg/L for F^- and 0.1 mg/L for Br^-, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, and SO_4^{2-} with a 100-µL sample loop and a 10-µmho full-scale setting on the conductivity detector. Similar values may be achieved by using a higher scale setting and an electronic integrator.

A4.3 Apparatus

A4.3.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

A4.3.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g; opaque fused silica, wide-form with an outside diameter of 29 mm at the top, a height of 19 mm, and a 5-mL capacity (Note A4.1), or nickel (Kawin capsule form), top diameter of 28 mm, 15 mm in height, and 5-mL capacity.

NOTE A4.1—Fused silica crucibles are much more economical and longer lasting than platinum. After each use, they should be scrubbed out with fine, wet emery cloth, heated to dull red heat over a burner, soaked in hot water for 1 h then dried and stored in a desiccator before reuse.

A4.3.3 *Firing Wire,* platinum, approximately No. 26 B and S gage.

A4.3.4 *Ignition Circuit* (Note A4.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A4.2—The switch in the ignition circuit should be of a type that remains open, except when held in closed position by the operator.

A4.3.5 *Nylon Sewing Thread,* or *Cotton Wicking*, white.

A4.3.6 *Ion Chromatograph,* including an injection valve, a sample loop, guard, separator, and suppressor columns, a temperature-compensated small-volume conductivity cell (6 µL or less), and a strip chart recorder capable of full-scale response of 2 s or less. An electronic peak integrator is optional. The ion chromatograph shall be capable of delivering 2 to 5 mL eluant/min at a pressure of 1400 to 6900 kPa.

A4.3.7 *Anion Separator Column,* with styrene divinylbenzene-based low-capacity pellicular anion-exchange resin capable of resolving Br^-, Cl^-, F^-, NO_3^-, NO_2^-, PO_4^{3-}, and SO_4^{2-}; 4 × 250 mm.

A4.3.8 *Guard Column,* identical to separator column except 4 × 50 mm, to protect separator column from fouling by particulates or organics.

A4.3.9 *Suppressor Column,* high-capacity cation-exchange resin capable of converting eluant and separated anions to their acid forms.

A4.3.10 *Syringe,* minimum capacity of 2 mL and equipped with a male pressure fitting.

A4.4 Reagents

A4.4.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[9] Other grades may be used provided it is first ascertained that the reagent has sufficiently high purity to permit its use without lessening the accuracy of the determination.

A4.4.2 *Deionized or Distilled Water,* free from interferences at the minimum detection limit of each constituent and filtered through a 0.2-µm membrane filter to avoid plugging columns.

A4.4.3 *Eluant Solution,* sodium bicarbonate-sodium carbonate, 0.003M $NaHCO_{3-}$ 0.0024M Na_2CO_3: dissolve 1.008 g $NaHCO_3$ and 1.0176 g Na_2CO_3 in water and dilute to 4 L.

A4.4.4 *Regenerant Solution 1,* H_2SO_4, 1 N, use this regenerant when suppressor is not a continuously regenerated one.

A4.4.5 *Regenerant Solution 2,* H_2SO_4, 0.025 N, dilute 2.8 mL conc H_2SO_4 to 4 L or 100 mL regenerant solution 1 to 4 L. Use this regenerant with continuous regeneration fiber suppressor system.

A4.4.6 *Standard Anion Solutions,* 1000 mg/L, prepare a series of standard anion solutions by weighing the indicated amount of salt, dried to a constant weight at 105°C, to 1000 mL. Store in plastic bottles in a refrigerator; these solutions are stable for at least one month.

Anion	Salt	Amount, g/L
Cl^-	NaCl	1.6485
F^-	NaF	2.2100
Br^-	NaBr	1.2876
NO_3^-	$NaNO_3$	1.3707
NO_2^-	$NaNO_2$	1.4998
PO_4^{3-}	KH_2PO_4	1.4330
SO_4^{2-}	K_2SO_4	1.8141

A4.4.7 *Combined Working Standard Solution, High Range*—Combine 10 mL of the Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-} standard anion solutions, 1 mL of the Br^-, and 100 mL of the SO_4^{2-} standard solutions, dilute to 1000 mL, and store in a plastic bottle protected from light; contains 10 mg/L each of Cl^- , F^-, NO_3^-, NO_2^-, and PO_4^{3-}, 1 mg Br^- /L, and 100 mg SO_4^{2-}/L. Prepare fresh daily.

A4.4.8 *Combined Working Standard Solution, Low Range*—Dilute 100 mL combined working standard solution, high range, to 1000 mL and store in a plastic bottle protected from light; contains 1.0 mg/L each Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-}, 0.1 mg Br^-/L, and 10 mg SO_4^{2-}/L. Prepare fresh daily.

A4.4.9 *Alternative Combined Working Standard Solutions*—Prepare appropriate combinations according to anion concentration to be determined. If NO_2^- and PO_4^{3-} are not included, the combined working standard is stable for one month.

A4.5 Sample Preparation

A4.5.1 *Penetrants, Developers, Emulsifiers, Magnetic Oils:*

A4.5.1.1 Weigh 50 g of test material into a 150-mm petri dish.

A4.5.1.2 Place the 150-mm petri dish into a 194°F [90°C] to 212°F [100°C] oven for 60 minutes.

A4.5.1.3 Allow the test material to cool to room temperature.

A4.5.2 *Solvent Cleaners:*

A4.5.2.1 Take the tare weight of an aluminum dish.

A4.5.2.2 Weigh 100 g of the cleaner into the aluminum dish.

A4.5.2.3 Place the aluminum dish on a hot plate in a fume hood.

A4.5.2.4 Let the material evaporate until the dish is nearly dry.

A4.5.2.5 Place the dish into a preheated oven from 194°F [90°C] to 212°F [100°C] for 10 minutes.

A4.5.2.6 Take the dish out of the oven and allow to cool.

A4.5.2.7 Reweigh the dish and record weight.

NOTE A4.3—*For Cleaners*—If the residue is less than 50 ppm, report the residue weight. If the weight is greater than 50 ppm, proceed with the bomb procedure.

A4.6 Decomposition Procedure

A4.6.1 *Preparation of Bomb and Sample*—Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 5 mL of Na_2CO_3/$NaHCO_3$ solution in the bomb, place the cover on the bomb, and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. The sample weight used should not exceed 1 g. If the sample is a solid, add a few drops of white oil at this time to ensure ignition of the sample.

NOTE A4.4—Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this it is recommended that for samples containing over 2 % chlorine, the sample weight be based on the following:

Chlorine content, %	Sample weight, g	White Oil weight, g
2 to 5	0.4	0.4
5 to 10	0.2	0.6
10 to 20	0.1	0.7
20 to 50	0.05	0.7

CAUTION: Do not use more than 1 g total of sample and white oil or other fluorine-free combustible material.

A4.6.2 *Addition of Oxygen*—Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (see Note A4.5) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A4.1.

NOTE A4.5—It is recommended to not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A4.6.3 *Combustion*—Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use.

A4.6.4 *Collection of Solution*—Remove the sample cup with clean forceps and rinse with deionized water and filter the washings into a 100-mL volumetric flask. Rinse the walls of the bomb shell with a fine stream of deionized water from a wash bottle, and add the washings through the filter paper to the flask. Next, rinse the bomb cover and terminals and add the washings through the filter into the volumetric flask. Finally, add deionized water to bring the contents of the flask to the line. Use aliquots of this solution for the ion chromatography (IC) analysis.

TABLE A4.1 Gage Pressures

Capacity of Bomb, mL	Gage Pressures, atm	
	mm^A	max
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

^{A} The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

A4.7 Procedure

A4.7.1 *System Equilibration*—Turn on ion chromatograph and adjust eluant flow rate to approximate the separation achieved in Fig. A4.1 (2 to 3 mL/min). Adjust detector to desired setting (usually 10 μmho) and let system come to equilibrium (15 to 20 min). A stable base line indicates equilibrium conditions. Adjust detector offset to zero-out eluant conductivity; with the fiber suppressor adjust the regeneration flow rate to maintain stability, usually 2.5 to 3 mL/min.

A4.7.1.1 Set up the ion chromatograph in accordance with the manufacturer's instructions.

A4.7.2 *Calibration*—Inject standards containing a single anion or a mixture and determine approximate retention times. Observed times vary with conditions but if standard eluant and anion separator column are used, retention always is in the order F^-, Cl^-, NO_2^-, PO_4^{3-}, Br^-, NO_3^-, and SO_4^{2-}. Inject at least three different concentrations for each anion to be measured and construct a calibration curve by plotting peak height or area against concentration on linear graph paper. Recalibrate whenever the detector setting is changed. With a system requiring suppressor regeneration, NO_2^- interaction with the suppressor may lead to erroneous NO_2^- results; make this determination only when the suppressor is at the same stage of exhaustion as during standardization or recalibrate frequently. In this type of system the water dip (see Note A4.5) may shift slightly during suppressor exhaustion and with a fast run column this may lead to slight interference for F^- or Cl^- . To eliminate this interference, analyze standards that bracket

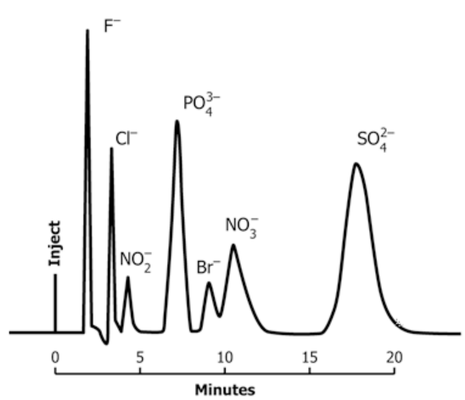

FIG. A4.1 Typical Anion Profile

the expected result or eliminate the water dip by diluting the sample with eluant or by adding concentrated eluant to the sample to give the same HCO_3^-/CO_3^{2-} concentration as in the eluant. If sample adjustments are made, adjust standards and blanks identically.

NOTE A4.6—Water dip occurs because water conductivity in sample is less than eluant conductivity (eluant is diluted by water).

A4.7.2.1 If linearity is established for a given detector setting, it is acceptable to calibrate with a single standard. Record the peak height or area and retention time to permit calculation of the calibration factor, F.

A4.7.3 *Sample Analysis*—Remove sample particulates, if necessary, by filtering through a prewashed 0.2-µm-pore-diam membrane filter. Using a prewashed syringe of 1 to 10 mL capacity equipped with a male luer fitting inject sample or standard. Inject enough sample to flush sample loop several times: for 0.1 mL sample loop inject at least 1 mL. Switch ion chromatograph from load to inject mode and record peak heights and retention times on strip chart recorder. After the last peak (SO_4^{2-}) has appeared and the conductivity signal has returned to base line, another sample can be injected.

A4.7.4 *Regeneration*—For systems without fiber suppressor regenerate with 1 N H_2SO_4 in accordance with the manufacturer's instructions when the conductivity base line exceeds 300 µmho when the suppressor column is on line.

A4.8 Calculation

A4.8.1 Calculate concentration of each anion, in mg/L, by referring to the appropriate calibration curve. Alternatively, when the response is shown to be linear, use the following equation:

$$C = H \times F \times D \tag{A4.1}$$

where:

C = mg anion/L,
H = peak height or area,
F = response factor − concentration of standard/height (or area) of standard, and
D = dilution factor for those samples requiring dilution.

A4.9 Precision and Bias

A4.9.1 Samples of reagent water to which were added the common anions were analyzed in 15 laboratories with the results shown in Table A4.2.

TABLE A4.2 Precision and Accuracy Observed for Anions at Various Concentration Levels in Reagent Water

Anion	Amount Added, mg/L	Amount Found, mg/L	Overall Precision, mg/L	Single-Operator Precision, mg/L	Significant Bias 95 % Level
F^-	0.48	0.49	0.05	0.03	No
F^-	4.84	4.64	0.52	0.46	No
Cl	0.76	0.86	0.38	0.11	No
Cl^-	17	17.2	0.82	0.43	No
Cl	455	471	46	13	No
NO_2	0.45	0.09	0.09	0.04	Yes, neg
NO_2	21.8	19.4	1.9	1.3	Yes, neg
Br^-	0.25	0.25	0.04	0.02	No
Br^-	13.7	12.9	1.0	0.6	No
PO_4^{3-}	0.18	0.10	0.06	0.03	Yes, neg
PO_4^{3-}	0.49	0.34	0.15	0.17	Yes, neg
NO_3^-	0.50	0.33	0.16	0.03	No
NO_3^-	15.1	14.8	1.15	0.9	No
SO_4^{2-}	0.51	0.52	0.07	0.03	No
SO_4^{2-}	43.7	43.5	2.5	2.2	No

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STANDARD GUIDE FOR USE OF UV-A AND VISIBLE LIGHT SOURCES AND METERS USED IN THE LIQUID PENETRANT AND MAGNETIC PARTICLE METHODS

SE-2297

(Identical with ASTM Specification E2297-15.)

Standard Guide for Use of UV-A and Visible Light Sources and Meters used in the Liquid Penetrant and Magnetic Particle Methods

1. Scope

1.1 This guide describes the use of UV-A/Visible light sources and meters used for the examination of materials by the liquid penetrant and magnetic particle processes. This guide may be used to help support the needs for appropriate light intensities and light measurement.

1.2 This guide also provides a reference:

1.2.1 To assist in the selection of light sources and meters that meet the applicable specifications or standards.

1.2.2 For use in the preparation of internal documentation dealing with liquid penetrant or magnetic particle examination of materials and parts.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E165 Practice for Liquid Penetrant Examination for General Industry
E709 Guide for Magnetic Particle Testing
E1208 Practice for Fluorescent Liquid Penetrant Testing Using the Lipophilic Post-Emulsification Process
E1209 Practice for Fluorescent Liquid Penetrant Testing Using the Water-Washable Process
E1210 Practice for Fluorescent Liquid Penetrant Testing Using the Hydrophilic Post-Emulsification Process
E1219 Practice for Fluorescent Liquid Penetrant Testing Using the Solvent-Removable Process
E1220 Practice for Visible Penetrant Testing Using Solvent-Removable Process
E1316 Terminology for Nondestructive Examinations
E1417 Practice for Liquid Penetrant Testing
E1418 Practice for Visible Penetrant Testing Using the Water-Washable Process
E1444 Practice for Magnetic Particle Testing
E3022 Practice For Measurement of Emission Characteristics and Requirements for LED UV-A Lamps Used in Fluorescent Penetrant and Magnetic Particle Testing

3. Terminology

3.1 The definitions that appear in E1316, relating to UV-A radiation and visible light used in liquid penetrant and magnetic particle examinations, shall apply to the terms used in this guide.

3.2 *Definitions:*

3.2.1 *high-intensity UV-A source*—a light source that produces UV-A irradiance greater than 10 000 $\mu W/cm^2$ (100 W/m^2) at 38.1 cm (15 in.).

3.2.2 *illuminance*—the amount of visible light, weighted by the luminosity function to correlate with human perception, incident on a surface, per unit area. Typically reported in units of lux (lx), lumens per square metre (lm/m^2) or footcandle (fc).

3.2.3 *irradiance*—the power of electromagnetic radiation incident on a surface, per unit area. Typically reported in units of watts per square metre (W/m^2) or microwatts per square centimetre ($\mu W/cm^2$).

3.2.4 *radiometer*—an instrument incorporating a sensor and optical filters to measure the irradiance of light over a defined range of wavelengths.

4. Summary of Guide

4.1 This guide describes the properties of UV-A and visible light sources used for liquid penetrant and magnetic particle examination. This guide also describes the properties of radiometers and light meters used to determine if adequate light levels (UV-A or visible, or both) are present while conducting a liquid penetrant or magnetic particle examination.

5. Significance and Use

5.1 UV-A and visible light sources are used to provide adequate light levels for liquid penetrant and magnetic particle examination. Radiometers and light meters are used to verify that specified light levels are available.

5.2 Fluorescence is produced by irradiating the fluorescent dyes/pigments with UV-A radiation. The fluorescent dyes/pigments absorb the energy from the UV-A radiation and re-emit light energy in the visible spectrum. This energy transfer allows fluorescence to be observed by the human eye.

5.3 UV-A light sources may emit visible light above 400 nm (400 Å), which may reduce the visiblity of fluorescent indications. High intensity UV-A light sources may cause UV fade, causing fluorescent indications to disappear.

6. Equipment

6.1 *Ultraviolet (UV)/Visible Light Spectrum*

6.1.1 UV light sources emit radiation in the ultraviolet section of the electromagnetic spectrum, between 180 nm (1800 Å) to 400 nm (4000 Å). Ultraviolet radiation is a part of the electromagnetic radiation spectrum between the violet/blue color of the visible spectrum and the weak X-ray spectrum. (See Fig. 1.)

6.1.2 The UV-A range is considered to be between 320 nm (3200 Å) and 400 nm (4000 Å).

6.1.3 The UV-B range (medium UV) is considered to be between 280 nm (2800 Å) and 320 nm (3200 Å).

6.1.4 The UV-C range (short UV) is considered to be between 180 nm (1800 Å) and 280 nm (2800 Å).

6.1.5 The visible spectrum is considered to be between 400 nm (4000 Å) and 760 nm (7600 Å).

6.2 *Mercury Vapor UV-A Sources*

6.2.1 Most UV-A sources utilize a lamp containing a mercury-gas plasma that emits radiation specific to the mercury atomic transition spectrum. There are several discrete element emission lines of the mercury spectrum in the ultraviolet section of the electromagnetic spectrum. The irradiance output is dependent on the gas pressure and the amount of mercury content. Higher values of gas pressure and mercury content result in significant increase in its UV emission. Irradiance output is also dependent on the input voltage and the age of the lamp bulb. As the bulb ages, mercury diffuses into the enclosing glass, causing the emission to decrease.

6.2.2 Mercury vapor UV-A sources used for NDT must have appropriate filters, either internal or external to the light source, to pass UV-A (6.1.2) and minimize visible light (6.1.5) output that is detrimental to the fluorescent inspection process. These UV-A pass filters should also block harmful UV-B (6.1.3) and UV-C (6.1.4) radiation.

6.2.3 Mercury vapor bulbs used for fluorescent NDT are generally low- or medium-pressure vapor sources.

6.2.3.1 Low-pressure bulbs (luminescent tubes) are coated with a special phosphor in order to maximize the UV-A output. Typically, low-pressure lamps are used in wash stations or for general UV-A lighting in the inspection room.

6.2.3.2 Medium-pressure bulbs do not have phosphor coatings but operate at higher electrical power levels, resulting in significantly higher UV-A output.

6.2.4 Medium-pressure lamps are typically used for fluorescent examination. A well designed medium pressure UV-A lamp with a suitable UV-A pass filter should emit less than 0.25 % to 1 % of its total intensity outside of the UV-A range. A typical lamp is based on the American National Standards Institute's Specification H 44 GS-R100, is a 100 watt mercury-vapor bulb in the Par 38 configuration, and normally uses a

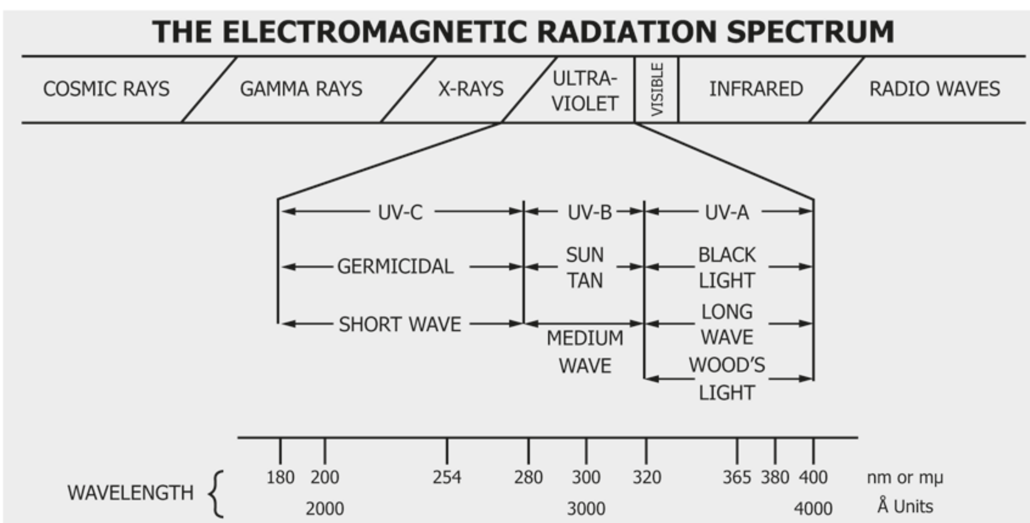

FIG. 1 The Electromagnetic Radiation Spectrum

Kopp 1041 or Kopp 1071 UV filter. Other lamps using the same bulb but with an alternate UV-A pass filter with similar transmission characteristics, or bulbs based on the Philips HPW 125-watt bulb will not differ greatly in UV-A output, but may produce more visible light in the blue/violet part of the spectrum.

NOTE 1—The Philips HPW 125-watt bulb has been restricted from use in the inspection station by many aerospace companies.

6.3 *UV-A Borescope, Fiberscope, Video-image-scope and Special UV-A Light Source Systems*

6.3.1 Borescopes, fiberscopes and video-image-scopes are thin rigid or flexible tubular optical telescopes. They are non destructive inspection quality control instruments for the visual detection of surface discontinuities in small bores, castings, pipe interiors, and on internal components of complex machinery.

6.3.2 The conventional optical glass fiber used as a light guide in borescopes, fiberscopes and video image scopes may be a poor transmitter of UV-A radiation. These fibers transmit white light in the 450 to 760 nm (4500 to 7600 Å) range, but do not effectively transmit light in the 350 to 380 nm (3500 to 3800 Å) range.

6.3.3 Three non traditional light guide materials for improved UV-A transmission in borescopes, fiberscopes or video-image-scopes, are liquid light guides, silica or quartz fibers, or special new glass fibers.

6.3.3.1 Silica or quartz fibers are good transmitters of UV-A energy, but are brittle and cannot be bent into a tight radius without breaking, nor can they accommodate the punishing stresses of repeated scope articulation.

6.3.3.2 Liquid light guides are very effective transmitters of UV-A, but have minimum diameter limitations at 2.5 mm and also exhibit problems with collapsing, kinking or loss of fluids.

6.3.3.3 A special glass fiber configuration offers the best UV performance plus durability. Special glass fiber light bundles combine high UV output with the necessary flexibility and durability required in these scopes.

6.4 *UV-A Pencil Lamps*

6.4.1 The pencil lamp is one of the smallest sources of UV-A radiation. It is generally a lamp coated with conversion phosphors that absorb the 254 nm (2540 Å) line of energy and convert this energy into a band peaking at 365 nm (3650 Å). The lamp may be encased in a tubular glass filter that absorbs visible light while transmitting maximum ultraviolet intensity. The pencil lamp is useful for fluorescent analysis and boroscopic inspection in inaccessible locations.

NOTE 2—Pencil Lamps produce low levels of UV-A radiation.

6.4.2 As with all metal vapor discharge lamps, the output of a quartz pencil lamp slowly decreases throughout its life. The actual useful life will primarily be dependent upon dust and other contaminants collecting on the lamp and its reflecting and transmissive elements. UV-A intensity loss also occurs as the lamp ages.

6.5 *High Intensity UV-A Light Sources*

6.5.1 *Metal Halide UV-A Sources:* The high intensity flood fixture normally uses a high wattage metal halide bulb. This lamp will also contain some type of specially coated parabolic reflector. The high intensity of this lamp will produce a great deal of heat, so some type of cooling fan must be used.

6.5.2 *Micro-Discharge Lamp UV-A Sources:* The MDL lamp uses a 35 watt metal halide bulb and therefore produces very little heat. Normally, a cooling fan is not required.

6.5.3 *Xenon Bulb UV-A Sources:* These lamps use a high-pressure arc bulb containing xenon gas or a mixture of mercury vapor and xenon gas.

6.5.4 High Intensity UV-A sources have broad emission spectra, which may include more than one peak within the UV-A range (6.1.2). For use in fluorescent NDT, these lamps must have appropriate filters, either internal or external to the light source, to pass UV-A (6.1.2) and minimize visible light (6.1.5) output that is detrimental to the fluorescent inspection process. These UV-A filters should also block harmful UV-B (6.1.3) and UV-C (6.1.4) radiation.

Warning—UV-A light sources may emit visible light above 400 nm (4000 Å), which may reduce the visibility of fluorescent indications. High intensity UV-A sources may cause UV fade, causing fluorescent indications to disappear.

6.6 *Light Emitting Diode (LED) UV-A Sources*

6.6.1 UV-A sources utilizing a single UV-A LED or an array of UV-A LEDs need to have emission characteristics that are comparable to those of other UV-A sources. For specific requirements, refer to Practice E3022.

Warning—Many UV-A LED lamps available at the retail level or purchased over the counter do not have emission characteristics that are acceptable for use in fluorescent liquid penetrant or magnetic particle examinations. See Practice E3022.

NOTE 3—Guide E709 and Practices E165, E1208, E1209, E1210, E1219, E1417, and E1444 provide UV-A light requirements for fluorescent magnetic particle and fluorescent penetrant inspection processes. See also the forthcoming E07 standard, Practice for Magnetic Particle Testing for General Industry.

6.7 *Visible Light Sources*

6.7.1 Visible light sources produce radiation in the 400 nm (4000 Å) to 760 nm (7600 Å) region in the electromagnetic spectrum. They have various intensities and different color responses that are easily observed by the human eye. The visible energy spectrum is easily absorbed by the eye's photoreceptors.

6.7.2 These photoreceptors are of two types, cones and rods.

6.7.2.1 Rods are highly sensitive to low intensities of light and contain only a single photopigment and is unable to discriminate color. The eye response under low intensity lighting is referred to as scotopic and uses rod photoreceptors.

6.7.2.2 Cone photoreceptors respond to higher light intensities and are referred to as photopic. The cones are composed of three different photopigments that are able to discriminate colors.

NOTE 4—Guide E709 and Practices E165, E1220, E1417, E1418, and E1444 provide visible light requirements for magnetic particle and penetrant examination. See also the forthcoming E07 standard, Practice for Magnetic Particle Testing for General Industry.

6.8 *Radiometers and Light Meters*

6.8.1 *UV-A Radiometer:*

6.8.1.1 Radiant energy is a physical quantity that can be measured directly in the laboratory by several types of optical radiation detectors; such as thermopiles, bolometers, pyroelectric instruments, and radiometric meters. All UV measuring devices are selective, and their sensitivity depends upon the wavelength of the radiation being measured.

6.8.1.2 The most practical measurement tool suitable for NDT fluorescent inspection is the radiometer. There are two types of radiometers, one with a digital and one with an analog response. The radiometer must have a filter system to limit the meter response to the UV-A range (6.1.2) with either a top-hat curve or a maximum response at 365 nm (3650 Å).

6.8.1.3 The digital meter is usually the meter of choice because of its ease of use. Another advantage is that the digital meter can measure high and low intensities of UV-A radiation without using screens or a mask to restrict the amount of UV-A radiation impinging on the sensor.

6.8.1.4 Digital meters generally have a sensor approximately 1 cm^2, and contain specific optical components that define the spectral range and convert the radiation into electrical current. The current is then processed by the instrument's solid-state electronics and displayed digitally.

6.8.2 *Visible Light Meters:*

6.8.2.1 Just like UV-A meters, there are two types of visible light meters, digital and analog. Visible light meters use photodiodes to measure illuminance. Because photodiodes may be sensitive to both visible light and UV, visible light meters for use in fluorescent NDT must have filters to limit the meter response to the visible spectrum (6.1.5).

Warning—Many meters available at the retail level or purchased over the counter do not have the proper filters to measure only visible light from 400 nm (4000 Å) to 760 nm (7600 Å) according to 6.1.5.

6.8.2.2 Unlike UV-A radiometers, visible light meters can provide illuminance readings in different units. Typical units are lux (lx) or foot-candles (fc). 1 foot candle equals 10.76 lux. Meter response in foot candles is generally used for NDT inspections in the United States.

6.8.2.3 Photodiodes, photometers, or visible light meters are not considered adequate for directly measuring the visible emission of UV-A lamps.

7. UV-A/Visible Light Measurement

7.1 *UV-A Light Measurement*

7.1.1 UV-A sources are evaluated by measuring the emission in the UV-A range (6.1.2) at a specific distance. Measurement distance is typically 38.1 cm (15 in.) from the face of the UV-A pass filter or front of the source to the surface of the sensor of the radiometer.

7.1.2 This measurement is performed for two reasons. The first is to develop a history on the UV-A source and the second is to ensure that the light output is in compliance with the specification in use.

7.1.3 If the distance is controlled, then the irradiation of the lamp can be observed and the degradation of the source can be recorded to ensure that the bulb (if used) is replaced in a timely manner. There are many types of fixtures that may be used to control the measured distance. The measurement should be taken from the face of the lamp (front of filter/source) to the top surface of the sensor. With the distance controlled, irradiation can be accurately measured. Many specifications define the required distance and light irradiation. A minimum of 1000 $\mu W/cm^2$ at 38.1 cm (15 in.) is typically specified.

NOTE 5—Turn on the UV-A lamp and allow it to warm up before measuring light intensities.

7.2 *Visible Light Contamination*

7.2.1 Most specifications will list the maximum visible light contamination allowable in the inspection area with few or no guidelines defining where the measurement should be taken. Since visible light contamination may interfere with UV-A inspection, the concern is not how much visible light is in the inspection area, but how much visible light is at the viewing surface of the part or in the inspector's eyes. It is recommended that the visible light contamination measurement be taken at the viewing surface. If visible light from a hole, seam, or other source impinges upon the inspector's eyes, it is recommended that the light be eliminated or reduced as much as possible.

NOTE 6—Visible light contamination can come from walls, ceilings, table tops, flooring, inspectors' clothing, computers, or light from outside the booth. (Any clothing that will fluoresce can cause white light contamination.)

7.3 *Visible Light Measurement*

7.3.1 In the case of visible light, most sources are either on or off. There is very little degradation, so the measurement is made to ensure that enough light is available to perform a good visual inspection. As discussed above, a visible light meter that measures the visible range of the electromagnetic spectrum should be used. The measurement should be taken from the front of the bulb to the top surface of the sensor. This distance may be fixed, or a minimum light intensity at the part surface may be required for performing a visible light inspection.

NOTE 7—Line voltage variations will cause differences in the measured light intensity. Tubular fluorescent white light intensity may fade with age and use.

8. Safety Considerations for the Use of UV-A Irradiation

8.1 *UV-A Exposure*

8.1.1 There have been a number of studies undertaken to provide a threshold limit for UV-A exposure. These studies however, have produced at times contradictory results, with no absolute values. For more information on threshold limit value studies, consult: The American Conference of Governmental Industrial Hygienists (ACGIH); ASNT Handbook, Volume 6

Magnetic Particle Testing; or the Chemical & Engineering News, August 4, 2003 edition, page 25.

NOTE 8—Photosensitive individuals or individuals exposed to photosensitizing agents, such as special medication may have adverse health effects when exposed to UV-A radiation.

8.2 *Safety Considerations for UV-A Lamps*

8.2.1 Although UV-A radiation is known to be relatively safe compared to UV-B or UV-C radiation, all operators and supervisors should be aware of certain safety precautions. Personnel using UV-A sources should avoid looking directly at the light with unshielded eyes. This could cause ocular fluorescence and consequently lower the user's ability to detect an indication. The filter on the UV-A source must always be in good condition and free from cracks, since radiation at wavelengths below 320 nm (3200 Å) is harmful and the visible light emitted will be detrimental to the inspection. It is recommended by most UV-A lamp manufacturers that users wear non-photochromatic eyewear (goggles or glasses) when performing inspections. The eyewear should be made of clear optical material (not tinted) and possess UV-blocking capabilities. It is also recommended by UV-A light manufacturers that users wear long- sleeve clothing, gloves and a hat to minimize direct exposure of radiation to the skin.

9. Keywords

9.1 electromagnetic spectrum; UV-A exposure limits; UV-A light; UV-A measurement; UV-A radiometers; UV-A sources; visible light contamination; visible light measurement; visible light meters; visible light sources

STANDARD PRACTICE FOR MEASUREMENT OF EMISSION CHARACTERISTICS AND REQUIREMENTS FOR LED UV-A LAMPS USED IN FLUORESCENT PENETRANT AND MAGNETIC PARTICLE TESTING

SE-3022

(Identical with ASTM Specification E3022-15.)

Standard Practice for Measurement of Emission Characteristics and Requirements for LED UV-A Lamps Used in Fluorescent Penetrant and Magnetic Particle Testing

1. Scope

1.1 This practice covers the procedures for testing the performance of ultraviolet A (UV-A), light emitting diode (LED) lamps used in fluorescent penetrant and fluorescent magnetic particle testing (see Guides E709 and E2297, and Practices E165/E165M, E1208, E1209, E1210, E1219, E1417/E1417M and E1444). This specification also includes reporting and performance requirements for UV-A LED lamps.

1.2 These tests are intended to be performed only by the manufacturer to certify performance of specific lamp models (housing, filter, diodes, electronic circuit design, optical elements, cooling system, and power supply combination) and also includes limited acceptance tests for individual lamps delivered to the user. This test procedure is not intended to be utilized by the end user.

1.3 This practice is only applicable for UV-A LED lamps used in the examination process. This practice is not applicable to mercury vapor, gas-discharge, arc or luminescent (fluorescent) lamps or light guides (for example, borescope light sources).

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E165/E165M Practice for Liquid Penetrant Examination for General Industry
E709 Guide for Magnetic Particle Testing
E1208 Practice for Fluorescent Liquid Penetrant Testing Using the Lipophilic Post-Emulsification Process
E1209 Practice for Fluorescent Liquid Penetrant Testing Using the Water-Washable Process
E1210 Practice for Fluorescent Liquid Penetrant Testing Using the Hydrophilic Post-Emulsification Process
E1219 Practice for Fluorescent Liquid Penetrant Testing Using the Solvent-Removable Process
E1316 Terminology for Nondestructive Examinations
E1348 Test Method for Transmittance and Color by Spectrophotometry Using Hemispherical Geometry
E1417/E1417M Practice for Liquid Penetrant Testing
E1444 Practice for Magnetic Particle Testing
E2297 Guide for Use of UV-A and Visible Light Sources and Meters used in the Liquid Penetrant and Magnetic Particle Methods

2.2 *Other Standards:*

ANSI/ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories
ANSI/NCSL Z540.3 Requirements for the Calibration of Measuring and Test Equipment

3. Terminology

3.1 *Definitions*—General terms pertaining to ultraviolet A (UV-A) radiation and visible light used in liquid penetrant and magnetic examination are defined in Terminology E1316 and shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *battery-powered hand-held lamp, n*—lamp powered by a battery used in either stationary or portable applications where line power is not available or convenient.

3.2.1.1 *Discussion*—These lamps may also have the option to be line-powered (that is, alternating current power supply). Smaller lamps, often referred to as "flashlights" or "torches" are used for portable examination of focused zones and often have a single LED.

3.2.2 *current ripple, n*—unwanted residual periodic variation (spikes or surges) of the constant current that drives the LED at a constant power level.

3.2.2.1 *Discussion*—Ripple is due to incomplete suppression of DC (peak to peak) variance resulting from the power supply, stability of regulation circuitry, circuit design, and quality of the electronic components.

3.2.3 *excitation irradiance, n*—irradiance calculated in the range of 347 nm and 382 nm. This corresponds to the range of wavelengths that effectively excite fluorescent penetrant dyes (i.e. greater than 80% of relative peak excitation).

3.2.4 *irradiance, E, n*—radiant flux (power) per unit area incident on a given surface. Typically measured in units of micro-watts per square centimeter ($\mu W/cm^2$).

3.2.5 *lamp model, n*—A lamp with specific design. Any change to the lamp design requires a change in model designation and complete qualification of the new model.

3.2.6 *light-emitting diode, LED, n*—solid state electronic devices consisting of a semiconductor or semiconductor elements that emit radiation or light when powered by a current.

3.2.6.1 *Discussion*—LEDs emit a relatively narrow bandwidth spectrum when a specific current flows through the chip. The emitted wavelengths are determined by the semiconductor material and the doping. The intensity and wavelength can change depending on the current, age, and chip temperature.

3.2.7 *line-powered lamp, n*—corded hand-held or overhead lamps that are line-powered and typically used for stationary inspections within a controlled production environment.

3.2.7.1 *Discussion*—These lamps are used for examination of both small and large inspection zones and consist of an LED array. Overhead lamps are used in a stationary inspection booth to flood the inspection area with UV-A radiation. Handheld lamps are used to flood smaller regions with UV-A radiation and can also be used in portable applications where line power is available.

3.2.8 *minimum working distance, n*—the distance from the inspection surface where the lamp beam profile begins to exhibit non-uniformity.

3.2.9 *transmittance, τ*—ratio of the radiant flux transmitted through a body to that incident upon it.

4. Significance and Use

4.1 UV-A lamps are used in fluorescent penetrant and magnetic particle examination processes to excite fluorophores (dyes or pigments) to maximize the contrast and detection of discontinuities. The fluorescent dyes/pigments absorb energy from the UV-A radiation and re-emit visible light when reverting to its ground state. This excitation energy conversion allows fluorescence to be observed by the human eye.

4.2 The emitted spectra of UV-A lamps can greatly affect the efficiency of dye/pigment fluorescent excitation.

4.3 Some high-intensity UV-A lamps can produce irradiance greater than 10 000 $\mu W/cm^2$ at 15 in. (381 mm). All high-intensity UV-A light sources can cause fluorescent dye fade and increase exposure of the inspector's unprotected eyes and skin to high levels of damaging radiation.

4.4 UV-A lamps can emit unwanted visible light and harmful UV radiation if not properly filtered. Visible light contamination above 400 nm can interfere with the inspection process and must be controlled to minimize reflected glare and maximize the contrast of the indication. UV-B and UV-C contamination must also be eliminated to prevent exposure to harmful radiation.

4.5 Pulse Width Modulation (PWM) and Pulse Firing (PF) of UV-A LED circuits are not permitted.

NOTE 1—The ability of existing UV-A radiometers and spectroradiometers to accurately measure the irradiance of pulse width modulated or pulsed fired LEDs and the effect of pulsed firing on indication detectability is not well understood.

5. Classifications

5.1 LED UV-A lamps used for nondestructive testing shall be of the following types:

5.1.1 *Type A*—Line-powered lamps (LED arrays for hand-held and overhead applications) (3.2.5 and 3.2.6).

5.1.2 *Type B*—Battery powered hand-held lamps (LED arrays for stationary and portable applications) (3.2.1).

5.1.3 *Type C*—Battery powered, handheld lamps (single LED flashlight or torch for special applications) (3.2.1, Discussion).

6. Apparatus

6.1 *UV-A Radiometer,* designed for measuring the irradiance of electromagnetic radiation. UV-A radiometers use a filter and sensor system to produce a bell-shaped (i.e. Gaussian) response at 365 nm (3650 Å) or top-hat responsivity centered near 365 nm (3650 Å). 365 nm (3650 Å) is the peak wavelength where most penetrant fluorescent dyes exhibit the greatest fluorescence. Ultraviolet radiometers shall be calibrated in accordance with ANSI/ISO/IEC 17025, ANSI/NCSL Z540.3, or equivalent. Radiometers shall be digital and provide a resolution of at least 5 $\mu W/cm^2$. The sensor front end aperture width or diameter shall not be greater than 0.5 in. (12.7 mm).

NOTE 2— Photometers or visible light meters are not considered adequate for measuring the visible emission of UV-A lamps which generally have wavelengths in the 400 nm to 450 nm range.

6.2 *Spectroradiometer,* designed to measure the spectral irradiance and absolute irradiance of electromagnetic emission sources. Measurement of spectral irradiance requires that such instruments be coupled to an integrating sphere or cosine corrector. This spectroradiometer shall have a resolution of at least 0.5 nm and a minimum signal-to-noise ratio of 50:1. The system shall be capable of measuring absolute spectral irradiance over a minimum range of 300 to 400 nm.

6.2.1 The system shall be calibrated using emission source reference standards.

6.3 *Spectrophotometer,* designed to measure transmittance or color coordinates of transmitting specimens. The system shall be able to perform a measurement of regular spectral transmittance over a minimum range of 300 to 800 nm.

7. Test Requirements

7.1 Lamp models used for nondestructive testing (NDT) shall be tested in accordance with the requirements of Table 1.

7.2 LEDs of UV-A Lamps shall be continuously powered with the LED drive current exhibiting minimum ripple (see 7.6.5). The projected beam shall also not exhibit any perceivable variability in projected beam intensity (i.e. strobing, flicker, etc.) (see 7.4.6).

7.3 *Maximum Irradiance*—Fixture the UV-A lamp 15 ± 0.25 in (381 ± 6 mm) above the surface of a flat, level workbench with the projected beam orthogonal to the workbench surface. The lamp face shall be parallel to the bench within ±0.25 in. (±6 mm). Ensure that battery-powered lamps (Types B and C) are fully charged. Turn on the lamp and allow to stabilize for 5 min. Place a UV-A radiometer, conforming to 6.1, on the workbench. Adjust the lamp position such that the filter of the lamp is 15.0 ± 0.25 in. (381 ± 12.7 mm) from the radiometer sensor. Scan the radiometer across the projected beam in two orthogonal directions to locate the point of maximum irradiance. Record the maximum irradiance value.

7.4 *Beam Irradiance Profile*—Affix the UV-A lamp above the surface of a flat, workbench with the projected beam orthogonal to the workbench surface.

7.4.1 Type A lamps shall be supplied with alternating current (ac) power supply at the manufacturer's rated power requirement. Power conditioning shall be used to ensure a stable power supply free of voltage spikes, ripples, or surges from the power supply network.

7.4.2 Type B and C lamps shall be powered using a constant voltage power direct current (DC) supply that provides constant DC power at the rated, fully charged battery voltage ±0.5 V.

7.4.3 The UV-A lamp shall be turned on and allowed to stabilize for a minimum of 30 min before taking measurements.

7.4.4 Place the UV-A radiometer on the workbench. Adjust the lamp position such that the face of the lamp is 15.0 ± 0.25 in. (381 ± 6 mm) from the radiometer sensor. Scan the radiometer across the projected beam in two orthogonal directions to locate the point of maximum irradiance. Record this location as the zero point. Using a 0.5-in. (12.7-mm) grid, translate the radiometer across the projected beam in 0.5-in. (12.7-mm) increments to generate a two-dimensional (2-D) plot of the beam profile (irradiance versus position). Position the radiometer using either an *x-y* scanner or by manually scanning. When manually scanning, use a sheet with 0.5-in. (1.27-cm) or finer squares and record the irradiance value in the center of each square. The beam irradiance profile shall extend to the point at which the irradiance drops below 200 μW/cm2.

7.4.5 Generate and report the 2-D plot of the beam irradiance profile (see Fig. 1). Map the range of irradiance from 200 to 1000 μW/cm^2, >1000 to 5000 μW/cm^2, >5000 to 10 000 μW/cm^2, >10 000 μW/cm^2. Report the minimum beam diameter at 1000 and 200 μW/cm^2.

NOTE 3—The defined ranges are minimums. Additional ranges are permitted.

7.4.6 During the observations of 7.4.1 through 7.4.5, note any output power variations indicated by perceived changes in projected beam intensity, flicker, or strobing. Any variations in observed beam intensity, flicker, or strobing are unacceptable.

7.5 *Minimum Working Distance*—Affix the lamp approximately 36 in. (900 mm) above a flat, level workbench covered with plain white paper. The projected beam shall be orthogonal to the covered workbench surface.

7.5.1 Measurements shall be performed in a darkened environment with less than 2 fc (21.5 lux) of ambient light and a stable temperature at 77 ± 5°F (25 ±3°C).

7.5.2 Ensure that battery-powered lamps are fully charged. The UV-A lamp shall be turned on and allowed to stabilize for a minimum of 30 min before taking measurements.

7.5.3 Observe the beam pattern produced on the paper. Lower the lamp until the beam pattern exhibits visible non-uniformity or reduction in intensity between the individual beams generated by each LED element or by irregularities in the lamp's optical path (Fig. 2). Measure the distance from the lamp face to workbench surface. Record this measurement as the minimum working distance.

7.6 *Temperature Stability—Emission Spectrum, Excitation Irradiance, Current Ripple*—Testing shall be performed in two steps, at ambient temperature conditions and at the maximum operating temperature reported by the manufacturer.

TABLE 1 UV-A LED Lamp Test Requirements by Lamp Model

Type	Test Requirements
A	7.3 Maximum Irradiance 7.4 Beam Irradiance Profile 7.5 Minimum Working Distance 7.6 Temperature Stability 7.6.1 Maximum Housing Temperature 7.6.4 Emission Spectrum 7.6.4.7 Peak Wavelength 7.6.4.8 Full Width Half Maximum (FWHM) 7.6.4.8 Longest Wavelength at Half Maximum 7.6.4.9 Excitation Irradiance 7.6.5 Current Ripple 7.8 Filter Transmittance
B, C	7.3 Maximum Irradiance 7.4 Beam Irradiance Profile 7.5 Minimum Working Distance 7.6 Temperature Stability 7.6.1 Maximum Housing Temperature 7.6.4 Emission Spectrum 7.6.4.8 Full Width Half Maximum (FWHM) 7.6.4.8 Longest Wavelength at Half Maximum 7.6.4.9 Excitation Irradiance 7.6.5 Current Ripple 7.7 Typical Battery Discharge Time and Discharge Plot 7.8 Filter Transmittance

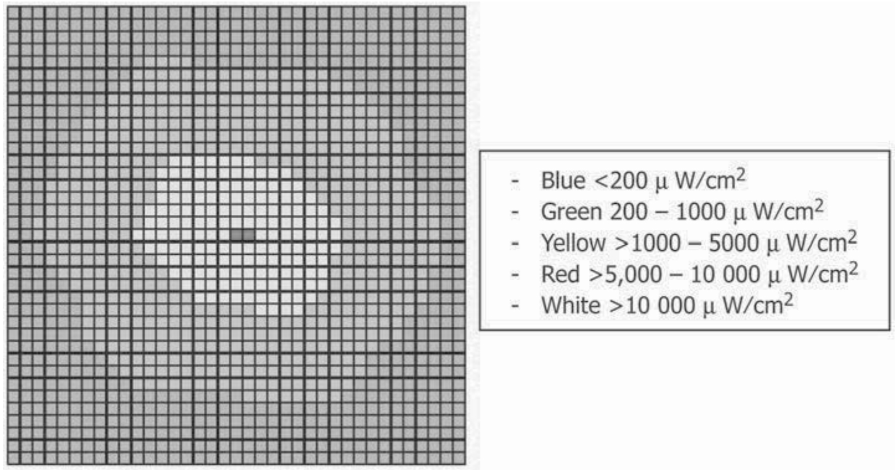

FIG. 1 Example of Beam Irradiance Profile

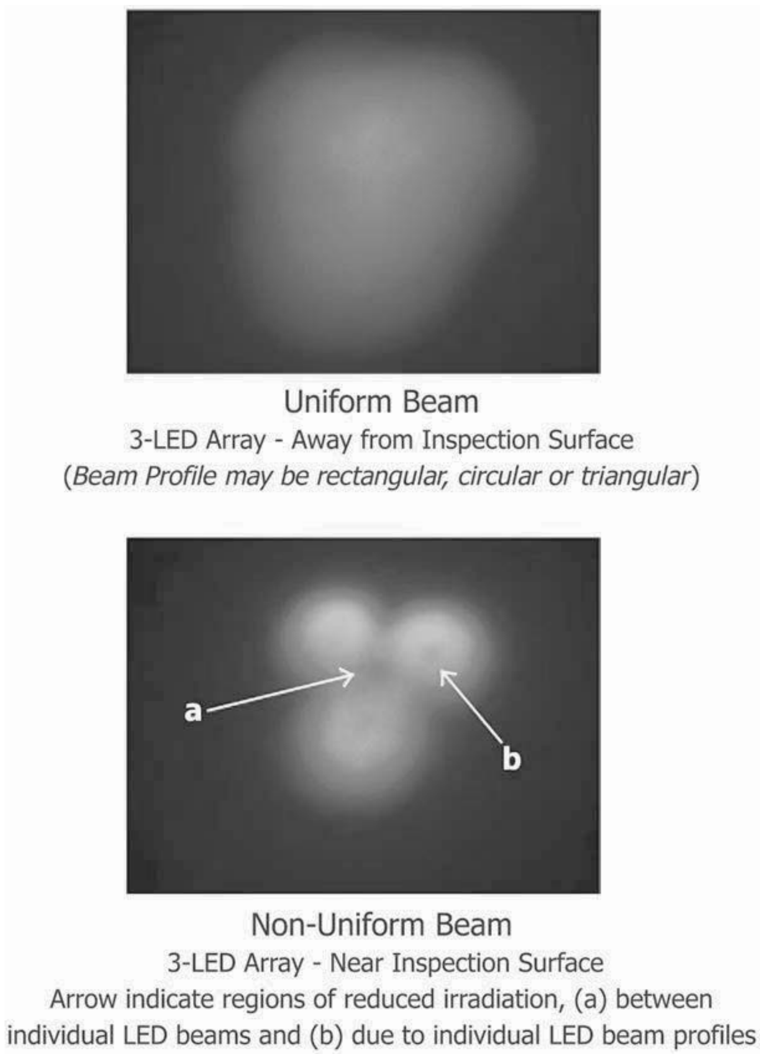

FIG. 2 Example of Univorm and Non-Uniform Projected Beams for Determining Minimum Working Distance

7.6.1 For ambient temperature testing conducted in 7.6.2 perform the following measurements:

(a) Emission spectrum (7.6.4.1 through 7.6.4.8),

(b) Excitation irradiance (7.6.4.9),

(c) Maximum lamp housing temperature, and

(d) Current ripple (7.6.5).

For elevated temperature tests conducted in 7.6.3 perform the following measurements:

(a) Emission spectrum (7.6.4.1 through 7.6.4.8),

(b) Excitation irradiance (7.6.4.9), and

(c) Current ripple (7.6.5).

7.6.2 *Ambient Temperature Test*—At lamp switch-on, perform the measurements defined by 7.6.4. Repeat the measurements every 30 min until the peak wavelength varies by no more than ±1 nm and the excitation irradiance does not vary more than 5% over three consecutive measurements. Once stabilized, measure the current ripple (7.6.5).

7.6.3 *Elevated Temperature Test*—Affix the lamp in an environmental chamber. Adjust the lamp and spectroradiometer position such that the filter of the lamp is 15.0 ± 0.25 in. (381 ± 6 mm) from the sensor aperture of the spectroradiometer. Adjust the lamp position such that the beam is centered on the sensor aperture. If the lamp uses a transformer or other power supply, those components shall also be placed in the environmental chamber. The change in temperature within the chamber shall not affect the accuracy of the measurements.

7.6.3.1 Set the chamber temperature to the maximum manufacturer's specified operating temperature of the lamp. At lamp switch on, perform the measurements defined by 7.6.4. Repeat the measurements every 30 min until the peak wavelength varies by no more than ±1 nm and the excitation irradiance does not vary more than 5% over three consecutive measurements. Once stabilized, measure the current ripple (7.6.5).

7.6.4 *Emission Spectrum Measurement*

7.6.4.1 Measurements shall be performed under dark laboratory conditions with a stable temperature.

7.6.4.2 A spectroradiometer conforming to 6.2 shall be used to collect data.

7.6.4.3 Power conditioning shall be used for both the spectroradiometer and Type A lamps to ensure a stable power supply free from voltage spikes, ripple, or surges from the power supply network.

7.6.4.4 Type B and C lamps may be powered using a constant voltage power DC supply that provides constant DC power at the rated, fully charged battery voltage ±0.5 V.

7.6.4.5 Adjust the lamp position such that the filter of the lamp is 15.0 ± 0.25 in. (381 ± 6 mm) from the spectroradiometer sensor aperture and the beam maximum irradiance is centered on the sensor aperture.

7.6.4.6 Measure and plot the emission spectrum between 300 and 400 nm (minimum range).

7.6.4.7 Determine the peak wavelength (i.e. wavelength with maximum spectral irradiance). See Fig. 3.

7.6.4.8 Calculate the width of the plotted spectrum at 50% of maximum spectral irradiance. Report this as the full-width-half maximum (FWHM) in nanometers. Also determine the longest wavelength at 50% of maximum spectral irradiance (i.e. half maximum). See Fig. 3.

7.6.4.9 Calculate the excitation irradiance in μW/cm², using:

$$\text{Excitation Irradiance} = \int_{347}^{382} N(\lambda)\, d\lambda \qquad (1)$$

where:

$N(\lambda)$ = spectral irradiance (μW/cm² nm) and
$d\lambda$ = 1 nm (maximum interval)

7.6.5 *Current Ripple—Stability of the LED Current*

7.6.5.1 *Purpose of the Measurement*—The LED drive current shall be stable and continuous and not result in pulsing or flickering during operation.

NOTE 4—High frequency current instability (kHz to MHz range) is

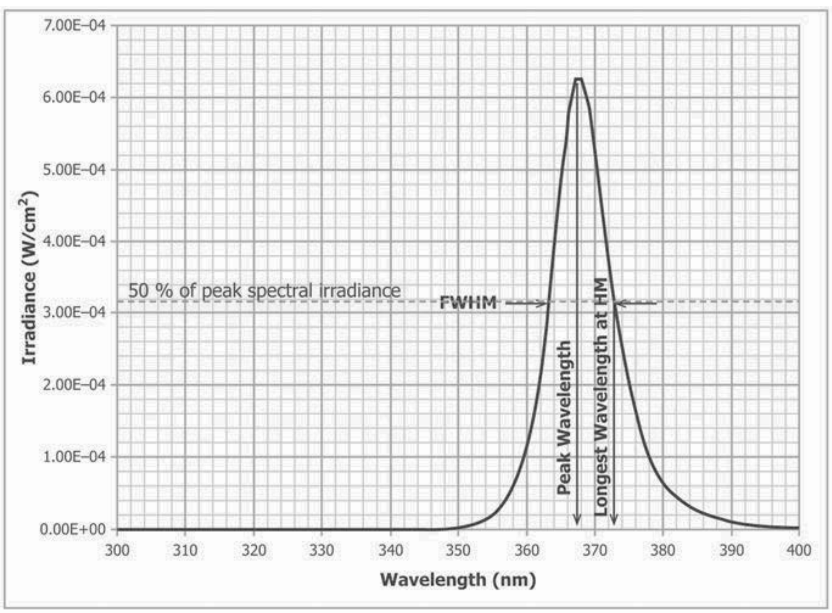

FIG. 3 Determination of Peak Wavelength, FWHM, and Longest Wavelength at Half Maximum (HM)

typically caused by switching of the regulated circuit, whereas low frequency instability (i.e. less than 0.5 Hz range) is often the result of external influences such line current variation or current regulation circuitry.

7.6.5.2 *Measurement of the LED Current*—The measurement of the variation of LED drive current shall be performed for every LED-circuit in a system without any changes to the circuit.

(1) The signal-to-noise ratio of the measured signal shall be at least 200:1.

(2) The physical vertical resolution of the measuring system (voltage scale) shall be at least 20 times greater than the ratio of the maximum allowed peak-to-peak-variation.

(3) The physical horizontal resolution of the measuring system (for the bandwidth/time scale) shall be at least 10 times the maximum switching frequency of the circuitry.

7.7 *Typical Battery Discharge Time (Type B and Type C Lamps):*

7.7.1 Affix the UV-A lamp 15 in. (381 mm) above a flat workbench with the projected beam orthogonal to the workbench surface. The battery shall be fully charged before starting measurements.

7.7.2 Place a UV-A radiometer, conforming to the requirements of 6.1, on the workbench. Adjust the lamp position such that the face of the lamp is 15.0 ± 0.25 in. (381 ± 6 mm) from the radiometer sensor.

7.7.3 Scan the radiometer across the projected beam to locate the point of maximum irradiance. Plot the elapsed time versus measured irradiance (see Fig. 4).

7.7.4 The typical battery discharge time is the total elapsed time from lamp turn-on to the time at which the lamp irradiance falls below 1000 μW/cm^2. Report the battery type, typical battery discharge time and discharge (time versus irradiance) plot.

7.8 *Filter Transmittance (Regular Spectral Transmittance)*—Filters shall be required on all UV-A lamps used for fluorescent penetrant and magnetic particle inspection to reduce visible light and UV-B and UV-C emission. The spectral transmission properties of the filter shall be measured between 300 and 800 nm using a spectrophotometer providing a resolution of 0.5 nm and 0.01 % of relative peak transmittance throughout the measurement range (see Practice E1348). A quartz tungsten halogen irradiance standard (i.e. tungsten coiled-coil filament enclosed in a quartz envelope) shall be used as the radiation source. Report the spectral transmittance curve and the nominal transmittance at 365 nm, 380 nm, 400 nm, 420 nm, 425 nm, 550 nm and 670 nm. An example of a typical spectral transmission curve for a UV-A lamp filter is shown in Fig. 5. Also measure and report the minimum filter thickness.

8. Acceptance Test

8.1 The following tests shall be performed on each lamp delivered to the customer (Table 2).

TABLE 2 Acceptance Test Requirements for Each UV-A LED Lamp

Type	Test Requirements
A, B, C	7.3 Maximum Irradiance 7.6.4 Emission Spectrum 7.6.4.7 Peak Wavelength 7.6.4.8 Full Width Half Maximum (FWHM) 7.6.4.8 Longest Wavelength at Half Maximum

8.1.1 Maximum irradiance (ambient conditions only) (7.3),

8.1.2 Emission spectrum (ambient conditions only) (7.6.4) at the stabilization time determined by 7.6.2,

8.1.3 Peak wavelength (7.6.4.7) at the stabilization time determined by 7.6.2,

8.1.4 FWHM (7.6.4.8) (Fig. 3), and

8.1.5 Longest wavelength at half maximum (7.6.4.8) (Fig. 3).

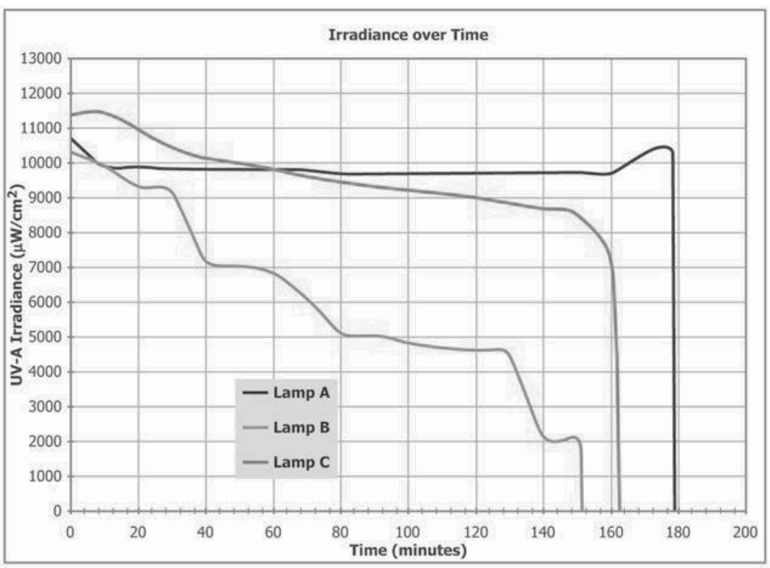

FIG. 4 Examples of Irradiance Change Over TIme Due to Battery Depletion

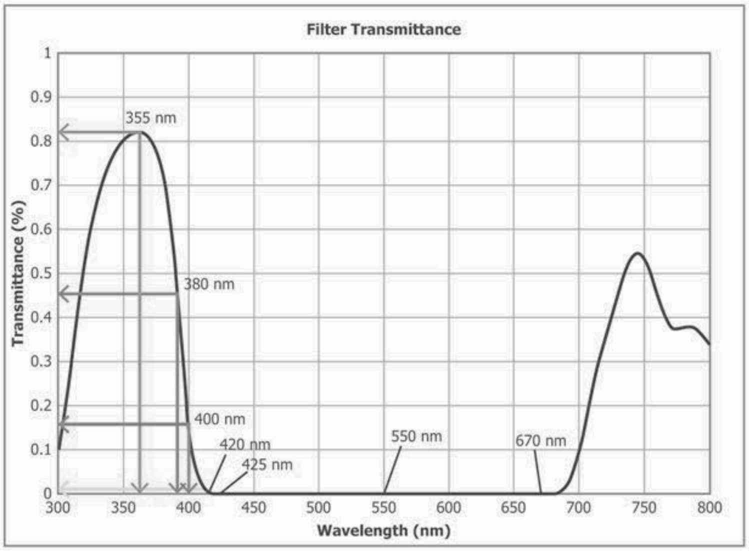

FIG. 5 Regular Spectral Transmittance for a Typical UV-A Lamp Filter

9. Performance Requirements

9.1 UV-A lamps tested in accordance with this specification shall meet the minimum performance requirements defined in Table 3.

10. Report

10.1 The manufacturer shall provide a certification of conformance that the lamp model meets the requirements of this standard. The certification shall be provided with each lamp supplied to the customer and shall include the results of the following lamp model tests.

10.1.1 Maximum irradiance (7.3),

10.1.2 Beam irradiance profile plot (7.4),

10.1.3 Minimum working distance (7.5),

10.1.4 Ambient temperature testing (switch-on and at stabilization):

10.1.4.1 Maximum lamp housing temperature at stabilization (7.6.1),

10.1.4.2 Emission spectrum (7.6.4.6),

10.1.4.3 Peak wavelength (7.6.4.7) (Fig. 3),

10.1.4.4 FWHM (7.6.4.8) (Fig. 3),

10.1.4.5 Longest wavelength at half maximum (7.6.4.8) (Fig. 3),

10.1.4.6 Excitation irradiance (7.6.4.9), and

10.1.4.7 Current ripple (at stabilization only) (7.6.5);

TABLE 3 UV-A LED Lamp Performance Requirements

Requirement	Type A	Type B	Type C
Beam Irradiance Profile (7.4) Hand-held Lamps	≥5 in. (127 mm) at ≥1000 μW/cm^2 (smallest dimension)	≥5 in. (127 mm) at ≥1000 μW/cm^2 (smallest dimension)	≥3 in. (76 mm) at ≥1000 μW/cm^2 (smallest dimension)
Beam Irradiance Profile (7.4) Overhead Lamps		Report	
Minimum Working Distance (7.5)		Report	
Maximum Housing Temperature at Ambient Conditions (7.6.1)		120°F (43.3°F)	
Peak Wavelength — Switch On, Ambient, and Elevated Temperature (7.6.4.7)		360 nm to 370 nm	
FWHM (7.6.4.8)		≤15 nm	
Longest Wavelength at Half Maximum (7.6.4.8)		377 nm	
Excitation Irradiance — Ambient and Elevated Temperature (7.6.4.9)		≥2000 μW/cm^2	
Current Ripple — Ambient and Elevated Temperature (7.6.5)		≤5% (peak-to-peak)	
Typical Battery Discharge Time (7.7)		Report	
Filter Transmittance (7.8)		380 nm ≤ 85% 400 nm ≤30% 420 nm ≤5% 425 to 670 nm ≤0.2%	

10.1.5 Elevated Temperature Conditions (at stabilization only):

10.1.5.1 Emission spectrum (7.6.4.6),

10.1.5.2 Peak wavelength (7.6.4.7) (Fig. 3),

10.1.5.3 FWHM (7.6.4.8) (Fig. 3),

10.1.5.4 Longest wavelength at half maximum (7.6.4.8) (Fig. 3),

10.1.5.5 Excitation irradiance (7.6.4.9),

10.1.5.6 Current ripple (at stabilization only) (7.6.5), and

10.1.5.7 Maximum operating temperature meeting the requirements of Table 3;

10.1.6 Battery type, typical battery discharge time, and discharge plot for Types B and C (7.7), and

10.1.7 Filter transmittance at 365 nm, 380 nm, 400 nm, 420 nm, 425 nm, 450 nm, 550 nm and 670 nm. Filter thickness (7.8).

10.2 The manufacturer shall provide with each lamp supplied to the customer a certification of conformance that the delivered lamp meets the technical requirements of Table 3 as tested in accordance with Section 8.

11. Keywords

11.1 fluorescent magnetic particle inspection; fluorescent penetrant inspection; irradiance; spectroradiometer; transmittance

ARTICLE 25
MAGNETIC PARTICLE STANDARDS

STANDARD TEST METHODS FOR NONDESTRUCTIVE MEASUREMENT OF DRY FILM THICKNESS OF NONMAGNETIC COATINGS APPLIED TO A FERROUS BASE

SD-1186

(Identical with ASTM Specification D1186-01.)

STANDARD TEST METHODS FOR NONDESTRUCTIVE MEASUREMENT OF DRY FILM THICKNESS OF NONMAGNETIC COATINGS APPLIED TO A FERROUS BASE

SD-1186

(Identical with ASTM D 1186-01)

1. Scope

1.1 These test methods cover the nondestructive measurement of the dry film thickness of nonmagnetic coatings applied over a ferrous base material using commercially available test instruments. The test methods are intended to supplement manufacturers' instructions for the manual operation of the gages and are not intended to replace them. They cover the use of instruments based on magnetic measuring principles only. Test Method A provides for the measurement of films using mechanical magnetic pull-off gages and Test Method B provides for the measurement of films using magnetic electronic gages.

1.2 These test methods are not applicable to coatings that will be readily deformable under the load of the measuring instruments, as the instrument probe must be placed directly on the coating surface to take a reading.

1.3 The values given in SI units of measurement are to be regarded as the standard. The values in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products

D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels

2.2 *Steel Structures Painting Council Standard:*

SSPC-PA2 Measurement of Dry Paint Thickness with Magnetic Gages

TEST METHOD A—MAGNETIC PULL-OFF GAGES

3. Summary of Test Method

3.1 Instruments complying with this test method measure thickness by using a spring calibrated to determine the force required to pull a magnet from a ferrous base coated with a nonmagnetic film. The instrument must be placed directly on the coating surface to take a reading.

3.2 The attractive force of the magnet to the substrate varies inversely with the thickness of the applied film. The spring tension required to overcome the attraction of the magnet to the substrate is shown on the instrument scale as the distance (in mils or microns) between the magnet and the substrate.

4. Significance and Use

4.1 Many coating properties are markedly affected by the thickness of the dry film such as adhesion, corrosion protection, flexibility, and hardness. To be able to compare results obtained by different operators, it is essential to know film thickness.

4.2 Most protective and high performance coatings are applied to meet a requirement or a specification for the dry-film thickness of each coat, or for the complete system, or both. Coatings must be applied within certain minimum and maximum thicknesses to fill their expected function. In addition to potential performance deficiencies, it is uneconomical to apply more material than necessary when coating large areas. This test method is used to measure film thickness of coatings on ferrous metals.

5. Apparatus

5.1 *Permanent Magnet,* small, either attached directly to a coil spring ("pencil" gage) or to a horizontal lever arm that is attached to a helical spring ("dial-type" gage). Increasing force is applied to the magnet by extending the coil spring in the first case or turning a graduated dial that coils the helical spring in the second. The readings obtained are shown directly on the instrument scale.

5.2 *Coating Thickness Standards,* with assigned values traceable to national standards are available from several sources, including most manufacturers of coating thickness gages.

6. Test Specimens

6.1 When this test method is used in the field, the specimen is the coated structure or article on which the thickness is to be evaluated.

6.2 For laboratory use, apply the material to be tested to panels of similar roughness, shape, thickness, composition and magnetic properties on which it is desired to determine the thickness.

NOTE 1 — Applicable test panel description and surface preparation methods are given in Practice D 609.

NOTE 2 — Coatings should be applied in accordance with Practices D 823 or as agreed upon between the contracting parties.

7. Verification of Calibration of Apparatus

7.1 Different gage manufacturers follow different methods of calibration adjustment. Verify calibration according to manufacturer's instructions.

7.2 The section of the type of standards used to verify calibration should be predicated upon which type provides the best and most appropriate calibration considering: type of gage, sample surface geometry, and contract requirements. Appendix X1 provides information helpful to making an informed selection of standards.

7.3 Following the manufacturer's operating instructions, measure the thickness of a series of calibration standards covering the expected range of coating thickness. To guard against measuring with an inaccurate gage, recheck the gage at regular intervals. That interval should be set by agreement between contracting parties and maintained throughout the control process.

NOTE 3 — Generally "Dial-type" instruments can be used in any position, while "pencil-type" instruments may be used in the vertical position only unless they have separate indicators for the horizontal and vertical positions. Follow the manufacturer's recommendations.

8. Procedure

8.1 Use the instrument only after calibration has been verified in accordance with Section 7.

8.2 Ensure that the coating is dry prior to use of the instrument.

8.3 Inspect the probe tip and surface to be measured to ensure that they are clean. Adherent magnetic filings or other surface contaminants will affect gage readings.

8.4 Take readings in locations free of electrical or magnetic fields. The location should also be free of vibration when using mechanical magnetic pull-off instruments.

8.5 The accuracy of the measurement can be influenced when made within 25 mm (1 in.) of the edge or right angle in the sample.

8.6 Measure the coating, following the manufacturer's instructions.

8.7 Verify calibration periodically to ensure that the instrument continues to read properly. If the instrument is found to be out of adjustment, remeasure the thicknesses taken since the last satisfactory calibration check was made.

8.8 Take a sufficient number of readings to characterize the surface.

8.8.1 For laboratory measurements, a recommended minimum is three for a 75 by 150- mm (3 by 6-in.) panel and more in proportion to size.

8.8.2 For field measurements, a recommended minimum is five determinations at random for every 10 m^2(100 ft^2) of surface area. Each of the five determinations should be the mean of three separate gage readings within the area of a 4-cm (1.5-in.) diameter circle.

8.9 Make measurements at least 13 mm ($\frac{1}{2}$ in.) away from any edge or corner of the specimen. If it is necessary to measure closer than 13 mm (½ in.), verify the effect (if any), the edge has on the mesurement.

NOTE 4 — or additional information describing the number of measurements to be taken on large structures, and on non-smooth surfaces, refer to SSPC PA-2.

9. Report

9.1 Report the following information:

9.1.1 Instrument used, serial number,

9.1.2 Range, and mean of the thickness readings, and

9.1.3 Depending upon the application, record the individual readings as well.

10. Precision and Bias

10.1 A new round-robin study was performed recently. Data are being analyzed statistically. When completed, the required "Repeatability and Repoducibility" sections of this test method will be written and the round- robin study documented in an ASTM research report.

10.2 *Bias* — The bias for Test Method A of this standard for measuring dry film thickness cannot be determined because each instrument has its own bias.

TEST METHOD B — ELECTRONIC GAGES

11. Summary of Test Method

11.1 Instruments complying with this test method measure thicknesses by placing a probe on the coated surface and use electronic circuitry to convert a reference signal into coating thickness.

11.2 Instruments of this type determine, within the probe or the instrument itself, changes in the magnitic flux caused by variations in the distance between the probe and the substrate.

12. Apparatus

12.1 The testing apparatus shall be an electrically operated instrument utilizing a probe that houses a permanent magnet or coil energized by alternating current that is placed directly on the surface. The coating thickness is shown on the instrument's display.

12.2 Coating thickness standards with assigned values traceable to national standards are available.

13. Test Specimens

13.1 See Section 6.

14. Calibration of Apparatus

14.1 See Section 7.

15. Procedure

15.1 See Section 8. Exclude steps 8.5 and 8.7.

16. Report

16.1 See Section 9.

17. Precision and Bias

17.1 *Precision* — See Section 10.

17.2 *Bias* — The bias for Test Method B of this standard for measuring dry film thickness cannot be determined because each instrument has its own bias.

18. Keywords

18.1 coating thickness; dry film thickness; magnetic gages; nondestructive thickness; paint thickness

APPENDIX

(Nonmandatory Information)

X1. CHARACTERISTICS AFFECTING GAGE READINGS

X1.1 It is always good practice to ensure the reliability of gage readings by performing a verification test periodically, either before or after critical determinations. This practice ensures that, not only is the gage reading correctly, but also that it is correctly calibrated to provide maximum accuracy of readings on the sample. Not all applications require this level of certainty so, while suggested, the inclusion of this practice is up to the contacting individuals to decide on implementation.

X1.2 Certain characteristics of samples may affect the accuracy of the calibrations. These include, but may not be limited to:

X1.2.1 Surface profile of the substrate (roughness),

X1.2.2 Surface profile of the coating,

X1.2.3 Thickness of the substrate,

X1.2.4 Geography of the sample surface (curves with small radii, small diameters, complex curves, etc.), and

X1.2.5 Any characteristic that affects the magnetic or eddy current permeability of the substrate or coating, such as residual magnetism, or lack of homogeneity of magnetic characteristics.

X1.3 Calibration done on smooth, polished standards ensure that a gage can be properly calibrated, and that calibration is appropriate for any measurements on samples of the same characteristics, but it may not be the best for measurements of samples that differ from the calibration materials. When possible, verification should be done on samples of known thickness of coating applied to substrates as similar as possible to the sample to be tested.

X1.4 It is not practical to provide known thickness standards for all possible sample configurations. An alternative method is to verify calibration on a bare substrate as similar as possible to the sample, using a nonmagnetic metal foil, plastic shim or film of known thickness to simulate a coating.

X1.5 In using this verification of calibration method, it is necessary to be aware of additional characteristics that can affect the measured values. Plastic or brass shim stock typically has an inherent curve. This curve can act as a leaf spring and cause a magnetic pull- off gage to be "pushed" off the surface prematurely, resulting in an incorrect reading.

X1.6 With some materials and thickness, it is possible that the shim will not lie flat, which will also cause an erroneous reading. Various techniques exist to minimize this effect, such as mounting the shim in a holder that maintains tension on the shim to eliminate the tendency of the shim to curve.

X1.7 Other factors experienced with plastic shims, which are not usually present with painted or plated calibration standards include (but are not limited to):

X1.7.1 Permanent creases in the shim due to folding,

X1.7.2 Air entrapment between the shim and substrate,

X1.7.3 Distortion due to environmental conditions, such as temperature, and

X1.7.4 Shim thickness inconsistency due to the pressure of the probe tip. This may be a permanent "dimple" in the shim.

X1.8 Even with these factors affecting potential accuracy of plastic shims, in many applications, verification of calibration using plastic shims on the sample to be measured, can be a more appropriate (accurate) calibration than using plated or painted standards.

X1.9 No matter what standards are used, they should be periodically verified to ensure the assigned value is correct. Even metal coated on metal can wear or be damaged to an extent that readings are affected.

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STANDARD GUIDE FOR MAGNETIC PARTICLE TESTING

SE-709

(Identical with ASTM Specification E709-15.)

Standard Guide for Magnetic Particle Testing

1. Scope

1.1 This guide covers techniques for both dry and wet magnetic particle testing, a nondestructive method for detecting cracks and other discontinuities at or near the surface in ferromagnetic materials. Magnetic particle testing may be applied to raw material, semifinished material (billets, blooms, castings, and forgings), finished material and welds, regardless of heat treatment or lack thereof. It is useful for preventive maintenance testing.

1.1.1 This guide is intended as a reference to aid in the preparation of specifications/standards, procedures and techniques.

1.2 This guide is also a reference that may be used as follows:

1.2.1 To establish a means by which magnetic particle testing, procedures recommended or required by individual organizations, can be reviewed to evaluate their applicability and completeness.

1.2.2 To aid in the organization of the facilities and personnel concerned in magnetic particle testing.

1.2.3 To aid in the preparation of procedures dealing with the examination of materials and parts. This guide describes magnetic particle testing techniques that are recommended for a great variety of sizes and shapes of ferromagnetic materials and widely varying examination requirements. Since there are many acceptable differences in both procedure and technique, the explicit requirements should be covered by a written procedure (see Section 21).

1.3 This guide does not indicate, suggest, or specify acceptance standards for parts/pieces examined by these techniques. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there should be a separate code, specification, or a specific agreement to define the type, size, location, degree of alignment and spacing, area concentration, and orientation of indications that are unacceptable in a specific part versus those which need not be removed before part acceptance. Conditions where rework or repair is not permitted should be specified.

1.4 This guide describes the use of the following magnetic particle method techniques.

1.4.1 Dry magnetic powder (see 8.4),

1.4.2 Wet magnetic particle (see 8.5),

1.4.3 Magnetic slurry/paint magnetic particle (see 8.5.7), and

1.4.4 Polymer magnetic particle (see 8.5.8).

1.5 *Personnel Qualification*—Personnel performing examinations in accordance with this guide should be qualified and certified in accordance with ASNT Recommended Practice No. SNT-TC-1A, ANSI/ASNT Standard CP-189, NAS 410, or as specified in the contract or purchase order.

1.6 *Nondestructive Testing Agency*—If a nondestructive testing agency as described in Practice E543 is used to perform the examination, the nondestructive testing agency should meet the requirements of Practice E543.

1.7 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.8 *Warning: Mercury has been designated by many regulatory agencies as a hazardous material that can cause serious medical issues. Mercury, or its vapor, has been demonstrated to be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Safety Data Sheet (SDS) for additional information. Users should be aware that selling mercury and/or mercury containing products into your state or country may be prohibited by law.*

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

E165/E165M Practice for Liquid Penetrant Examination for General Industry

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

E1444/E1444M Practice for Magnetic Particle Testing

2.2 *Society of Automotive Engineers (SAE): Aerospace Materials Specifications:*

AMS 2300 Premium Aircraft Quality Steel Cleanliness Magnetic Particle Inspection Procedure

AMS 2301 Aircraft Quality Steel Cleanliness Magnetic Particle Inspection Procedure

AMS 2303 Aircraft Quality Steel Cleanliness Martensitic Corrosion Resistant Steels Magnetic Particle Inspection Procedure

AMS 2641 Vehicle Magnetic Particle Inspection

AMS 3040 Magnetic Particles, Non-fluorescent, Dry Method

AMS 3041 Magnetic Particles, Non-fluorescent, Wet Method, Oil Vehicle, Ready to Use

AMS 3042 Magnetic Particles, Non-fluorescent, Wet Method, Dry Powder

AMS 3043 Magnetic Particles, Non-fluorescent, Oil Vehicle, Aerosol Packaged

AMS 3044 Magnetic Particles, Fluorescent, Wet Method, Dry Powder

AMS 3045 Magnetic Particles, Non-fluorescent, Wet Method, Oil Vehicle, Ready to Use

AMS 3046 Magnetic Particles, Non-fluorescent, Wet Method, Oil Vehicle, Aerosol Packaged

AMS 5062 Steel, Low Carbon Bars, Forgings, Tubing, Sheet, Strip, and Plate 0.25 Carbon, Maximum

AMS 5355 Investment Castings

AMS-I-83387 Inspection Process, Magnetic Rubber

AS 4792 Water Conditioning Agents for Aqueous Magnetic Particle Inspection

AS 5282 Tool Steel Ring Standard for Magnetic Particle Inspection

AS 5371 Reference Standards Notched Shims for Magnetic Particle Inspection

2.3 *American Society for Nondestructive Testing:*

SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

CP-189 ASNT Qualification and Certification of Nondestructive Testing Personnel

2.4 *Federal Standards:*

A-A-59230 Fluid, Magnetic Particle Inspection, Suspension

FED-STD 313 Material Safety Data Sheets Preparation and the Submission of

2.5 *OSHA Document:*

29CFR 1910.1200 Hazard Communication

2.6 *AIA Documents:*

NAS 410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 For definitions of terms used in the practice, refer to Terminology E1316.

4. Summary of Guide

4.1 *Principle*—The magnetic particle method is based on establishing a magnetic field with high flux density in a ferromagnetic material. The flux lines must spread out when they pass through non-ferromagnetic material such as air in a discontinuity or an inclusion. Because flux lines can not cross, this spreading action may force some of the flux lines out of the material (flux leakage). Flux leakage is also caused by reduction in ferromagnetic material (cross-sectional change), a sharp dimensional change, or the end of the part. If the flux leakage is strong enough, fine magnetic particles will be held in place and an accumulation of particles will be visible under the proper lighting conditions. While there are variations in the magnetic particle method, they all are dependent on this principle, that magnetic particles will be retained at the locations of magnetic flux leakage. The amount of flux leakage at discontinuities depends primarily on the following factors: flux density in the material, and size, orientation, and proximity to the surface of a discontinuity. With longitudinal fields, all of the flux lines must complete their loops though air and an excessively strong magnetic field may interfere with examination near the flux entry and exit points due to the high flux-density present at these points.

4.2 *Method*—While this practice permits and describes many variables in equipment, materials, and procedures, there are three steps essential to the method:

4.2.1 The part must be magnetized.

4.2.2 Magnetic particles of the type designated in the contract/purchase order/specification should be applied while the part is magnetized or immediately thereafter.

4.2.3 Any accumulation of magnetic particles must be observed, interpreted, and evaluated.

4.3 *Magnetization:*

4.3.1 *Ways to Magnetize*—A ferromagnetic material can be magnetized either by passing an electric current through the material or by placing the material within a magnetic field originated by an external source. The entire mass or a portion of the mass can be magnetized as dictated by size and equipment capacity or need. As previously noted, in order to be detectable, the discontinuity must interrupt the normal path of the magnetic field lines. If a discontinuity is open to the surface, the flux leakage attracting the particles will be at the maximum value for that particular discontinuity. When that same discontinuity is below the surface, flux leakage evident on the surface will be a lesser value.

4.3.2 *Field Direction*—If a discontinuity is oriented parallel to the magnetic field lines, it may be essentially undetectable. Therefore, since discontinuities may occur in any orientation, it may be necessary to magnetize the part or the area of interest twice or more sequentially in different directions by the same method or a combination of different methods (see Section 13) to induce magnetic field lines in a suitable direction in which to perform an adequate examination.

4.3.3 *Field Strength*—The magnetic field must be of sufficient strength to indicate those discontinuities which are unacceptable, yet must not be so strong that an excess of local particle accumulation masks relevant indications (see Section 14).

4.4 *Types of Magnetic Particles and Their Use*—There are various types of magnetic particles available for use in magnetic particle testing. They are available as dry powders (fluorescent and nonfluorescent) ready for use as supplied (see 8.4), powder concentrates (fluorescent and nonfluorescent) for dispersion in water or suspending in light petroleum distillates (see 8.5), magnetic slurries/paints (see 8.5.7), and magnetic polymer dispersions (see 8.5.8).

4.5 *Evaluation of Indications*—When the material to be examined has been properly magnetized, the magnetic particles have been properly applied, and the excess particles properly removed, there will be accumulations of magnetic particles remaining at the points of flux leakage. These accumulations show the distortion of the magnetic field and are called indications. Without disturbing the particles, the indications must be examined, classified, compared with the acceptance standards, and a decision made concerning the disposition of the material that contains the indication.

4.6 *Typical Magnetic Particle Indications:*

4.6.1 *Surface Discontinuities*—Surface discontinuities, with few exceptions, produce sharp, distinct patterns (see Annex A1).

4.6.2 *Near-surface Discontinuities*—Near-surface discontinuities produce less distinct indications than those open to the surface. The patterns tend to be broad, rather than sharp, and the particles are less tightly held (see Annex A1).

5. Significance and Use

5.1 The magnetic particle method of nondestructive testing indicates the presence of surface and near-surface discontinuities in materials that can be magnetized (ferromagnetic). This method can be used for production examination of parts/components or structures and for field applications where portability of equipment and accessibility to the area to be examined are factors. The ability of the method to find small discontinuities can be enhanced by using fluorescent particles suspended in a suitable vehicle and by introducing a magnetic field of the proper strength whose orientation is as close as possible to 90° to the direction of the suspected discontinuity (see 4.3.2). A smoother surface or a pulsed current improves mobility of the magnetic particles under the influence of the magnetic field to collect on the surface where magnetic flux leakage occurs.

6. Equipment

6.1 *Types*—There are a number of types of equipment available for magnetizing ferromagnetic parts and components. With the exception of a permanent magnet, all equipment requires a power source capable of delivering the required current levels to produce the magnetic field. The current used dictates the sizes of cables and the capability of relays, switching contacts, meters and rectifier if the power source is alternating current.

6.2 *Portability*—Portability, which includes the ability to hand carry the equipment, can be obtained from yokes, portable coils with power supplies, and capacitor discharge power supplies with cables. Generally, portable coils provide

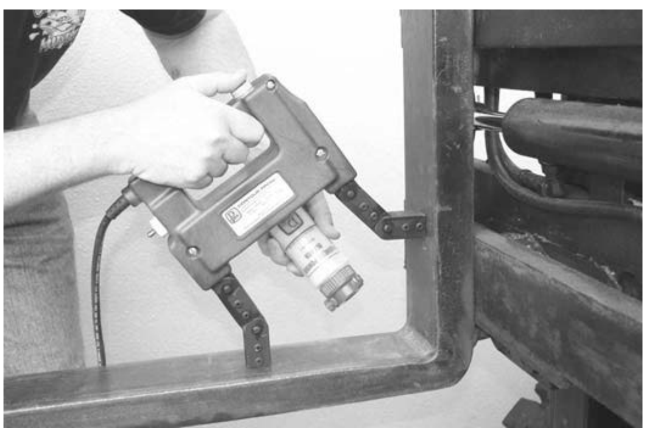


FIG. 1 Yoke Method of Part Magnetization

high magnetizing forces by using higher numbers of turns to compensate for their lower current flow. Capacitor discharge units use high current storage capacity and provide these high current levels for only a very short duration.

6.3 *Yokes*—Yokes are usually C-shaped electromagnets which induce a magnetic field between the poles (legs) and are used for local magnetization (Fig. 1). Many portable yokes have articulated legs (poles) that allow the legs to be adjusted to contact irregular surfaces or two surfaces that join at an angle.

6.3.1 *Permanent Magnets*—Permanent magnets are available but their use may be restricted for many applications. This restriction may be due to application impracticality, or due to the specifications governing the examination. Permanent magnets can lose their magnetic field generating capacity by being partially demagnetized by a stronger flux field, being damaged, or dropped. In addition, the particle mobility created by AC current or HW current pulsations produced by electromagnetic yokes are not present. Particles, steel filings, chips, and scale clinging to the poles can create a housekeeping problem.

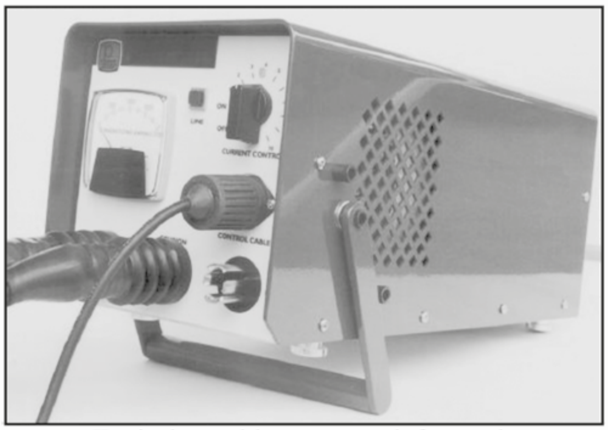
6.4 *Prods*—Prods are used for local magnetizations, see Fig. 2. The prod tips that contact the piece should be aluminum, copper braid, or copper pads rather than solid copper. With solid copper tips, accidental arcing during prod placement or removal can cause copper penetration into the surface which may result in metallurgical damage (softening, hardening, cracking, etc.). Open-circuit voltages should not exceed 25 V.

6.4.1 *Remote Control Switch*—A remote-control switch, which may be built into the prod handles, should be provided to permit the current to be turned on after the prods have been properly placed and to turn it off before the prods are removed in order to prevent arcing (arc burns).

6.5 *Bench Unit*—A typical bench type unit is shown in Fig. 3. The unit normally is furnished with a head/tailstock combination along with a fixed coil (see Fig. 4).

6.6 *UV-A Lights (Black Light)*—which are portable, handheld, permanently mounted or fixed, and used to examine parts, should be checked for output at the frequency specified in Table 2 and after bulb replacement. A longer period may be used if a plan justifying this extension is prepared by the NDT facility or its delegate. Minimum acceptable intensity is 1000 μW/cm^2 at the examination surface.

NOTE 1—When using a mercury vapor style lamp, a change in line



Typical portable power pack for prods

Typical Single Prod Set

Typical Double Prod Set

FIG. 2

FIG. 3 Bench Unit

voltage greater than ±10 % can cause a change in light output and consequential loss of inspection performance. A constant voltage transformer may be used where there is evidence of voltage changes greater than 10 %.

NOTE 2—Some UV-A sources other than mercury vapor, for example, micro-discharge, LED, etc., have been shown to have emission characteristics such as excessive visible light and UV intensity that may result in fluorescent fade, veiling glare, etc., all of which can significantly degrade examination reliability.

6.6.1 UV-A lights that use a UV-A LED source shall produce a peak wavelength at 365 to 370 nanometers as measured with a spectroradiometer. When requested, the manufacturer shall provide a certification thereof.

6.6.2 Battery-powered UV-A lights used to examine parts shall have their intensity measured prior to use and after each use.

6.7 *Equipment Verification*—See Section 20.

7. Examination Area

7.1 *Light Intensity for Examination*—Magnetic indications found using nonfluorescent particles are examined under visible light. Indications found using fluorescent particles must be examined under UV-A (black) light. This requires a darkened area with accompanying control of the visible light intensity.

7.1.1 *Visible Light Intensity*—The intensity of the visible light at the surface of the part/work piece undergoing nonfluorescent particle examination is recommended to be a minimum of 100 foot candles (1076 lux).

7.1.1.1 *Field Examinations—For some field examinations* using nonfluorescent particles, visible light intensities as low as 50 foot candles (538 lux) may be used when agreed on by the contracting agency.

7.1.1.2 *Ambient Visible Light*—The intensity of ambient visible light in the darkened area where fluorescent magnetic particle testing is performed is recommended to not exceed 2 foot candles (21.5 lux).

7.1.2 *UV-A (Black) Light:*

7.1.2.1 *UV-A (Black Light) Intensity*—The UV-A irradiance at the examination surface is recommended to not be less than 1000 $\mu W/cm^2$ when measured with a suitable UV-A radiometer.

7.1.2.2 *UV-A (Black Light) Warm-up*—When using a mercury vapor bulb, allow the UV-A (black) light to warm up for a minimum of five minutes prior to its use or measurement of the intensity of the ultraviolet light emitted.

7.1.3 *Dark Area Eye Adaptation*—The generally accepted practice is that an inspector be in the darkened area at least one (1) minute so that his or her eyes will adapt to dark viewing prior to examining parts under UV illumination. (**Warning—** Photochromic or permanently tinted lenses should not be worn during examination.)

7.2 *Housekeeping*—The examination area should be kept free of interfering debris. If fluorescent materials are involved, the area should also be kept free of fluorescent objects not related to the part/piece being examined.

8. Magnetic Particle Materials

8.1 *Magnetic Particle Properties:*

8.1.1 *Dry Particle Properties*—AMS 3040 describes the generally accepted properties of dry method particles.

8.1.2 *Wet Particle Properties*—The following documents describe the generally accepted properties of wet method particles in their various forms:

AMS 3041 Magnetic Particles, Non-fluorescent, Wet Method, Oil Vehicle, Ready to Use

AMS 3042 Magnetic Particles, Non-fluorescent, Wet Method, Dry Powder

AMS 3043 Magnetic Particles, Non-fluorescent, Oil Vehicle, Aerosol Packaged

AMS 3044 Magnetic Particles, Fluorescent, Wet Method, Dry Powder

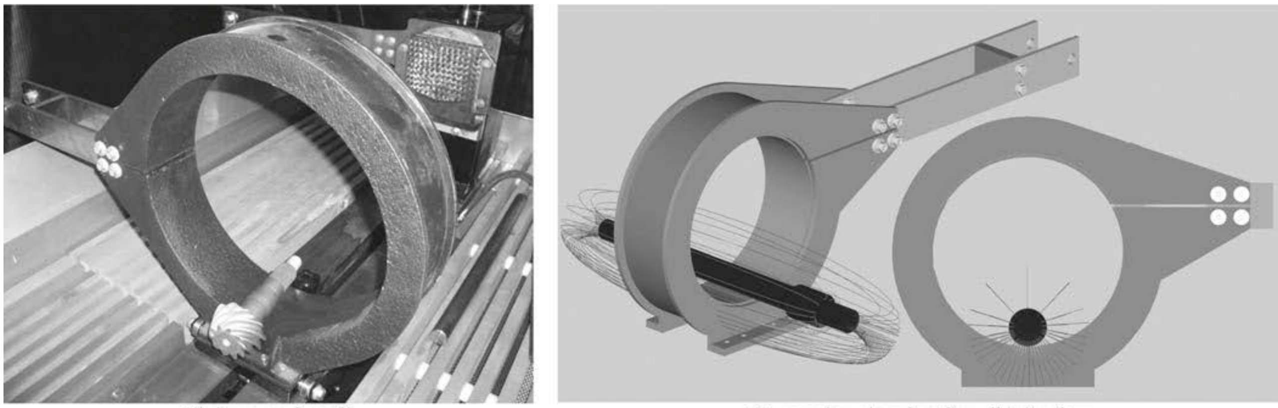
AMS 3045 Magnetic Particles, Non-fluorescent, Wet Method, Oil Vehicle, Ready to Use

AMS 3046 Magnetic Particles, Non-fluorescent, Wet Method, Oil Vehicle, Aerosol Packaged

8.1.3 *Suspension Vehicle*—The suspension vehicle for wet-method examination may be either a light oil distillate fluid (refer to AMS 2641 or A-A-52930) or a conditioned water vehicle (refer to AS 4792).

8.2 *Particle Types*—The particles used in either dry or wet magnetic particle testing techniques are basically finely divided ferromagnetic materials which have been treated to impart color (fluorescent and nonfluorescent) in order to make them highly visible (contrasting) against the background of the surface being examined. The particles are designed for use either as a free flowing dry powder or for suspension at a given concentration in a suitable liquid medium.

8.3 *Particle Characteristics*—The magnetic particles must have high permeability to allow ease of magnetizing and attraction to the site of the flux leakage and low retentivity so they will not be attracted (magnetic agglomeration) to each other. Control of particle size and shape is required to obtain consistent results. The particles should be nontoxic, free from rust, grease, paint, dirt, and other deleterious materials that might interfere with their use; see 20.5 and 20.6. Both dry and wet particles are considered safe when used in accordance with the manufacturer's instructions. They generally afford a very low hazard potential with regard to flammability and toxicity.



Pinion gear in coil

Conception showing flux distribution with part in the bottom of the coil

FIG. 4 Bench Fixed Coil and Field Distribution

8.4 *Dry Particles*—Dry magnetic powders are designed to be used as supplied and are applied by spraying or dusting directly onto the surface of the part being examined. They are generally used on an expendable basis because of the requirement to maintain particle size and control possible contamination. Reuse is not a normal practice. Dry powders may also be used under extreme environmental conditions. They are not affected by cold; therefore examination can be carried out at temperatures that would thicken or freeze wet baths. They are also heat resistant; some powders may be usable at temperatures up to 600°F (315°C). Some colored, organic coatings applied to dry particles to improve contrast lose their color at temperatures this high, making the contrast less effective. Fluorescent dry particles cannot be used at this high a temperature; the manufacturer should be contacted for the temperature limitations (see 15.1.2).

8.4.1 *Advantages*—The dry magnetic particle technique is generally superior to the wet technique for detection of near-surface discontinuities on parts with a gross indication size. Refer to 8.5.1: (a) for large objects when using portable equipment for local magnetization; (b) superior particle mobility is obtained for relatively deep-seated flaws using half-wave rectified current as the magnetizing source; (c) ease of removal.

8.4.2 *Disadvantages*—The dry magnetic particle technique; (a) cannot be used in confined areas without proper safety breathing apparatus; (b) can be difficult to use in overhead magnetizing positions; (c) does not always leave evidence of complete coverage of part surface as with the wet technique; (d) is likely to have lower production rates than the wet technique; and (e) is difficult to adapt to any type of automatic system.

8.4.3 *Nonfluorescent Colors*—Although dry magnetic particle powder can be almost any color, the most frequently employed colors are light gray, black, red, or yellow. The choice is generally based on maximum contrast with the surface to be examined. The examination is done under visible light.

8.4.4 *Fluorescent*—Fluorescent dry magnetic particles are also available, but are not in general use primarily because of their higher cost and use limitations. They require a UV-A (black) light source and a darkened work area. These requirements are not often available in the field-type locations where dry magnetic particle examinations are especially suitable.

8.4.5 *Dual Response*—Dual response particles are available that are readily detectable in visible light and also display fluorescence when viewed under UV-A or a combination visible and UV-A. Use in accordance with the manufacturer's recommendations.

8.5 *Wet Particle Systems*—Wet magnetic particles are designed to be suspended in a vehicle such as water or light petroleum distillate at a given concentration for application to the examination surface by flowing, spraying, or pouring. They are available in both fluorescent and nonfluorescent concentrates. In some cases the particles are premixed with the suspending vehicle by the supplier, but usually the particles are supplied as a dry concentrate or paste concentrate which is mixed with the distillate or water by the user. The suspensions are normally used in wet horizontal magnetic particle equipment in which the suspension is retained in a reservoir and recirculated for continuous use. The suspension may also be used on an expendable basis dispensed from an aerosol or other suitable dispensers.

8.5.1 *Primary Use*—Because the particles used are smaller, wet method techniques are generally used to locate smaller discontinuities than the dry method is used for. The liquid vehicles used may not perform satisfactorily when their viscosity exceeds 5cSt (5 mm^2/s) at the operating temperature. If the suspension vehicle is a hydrocarbon, its flash point limits the top temperature of usage. Mixing equipment for bulk reservoirs or manual agitation for portable dispensers is usually required to keep wet method particles uniformly in suspension.

8.5.2 *Where Used*—The wet fluorescent method usually is performed indoors or in areas where shelter and ambient light level can be controlled and where proper application equipment is available.

8.5.3 *Color*—The color chosen for any given examination should be one that best contrasts with the test surface. Because contrast is invariably higher with fluorescent materials, these are utilized in most wet process examinations. Fluorescent wet method particles normally glow a bright yellow-green when viewed under UV-A (black) light, although other colors are available. Non-fluorescent particles are usually black or reddish brown, although other colors are available. Dual response particles are available that are readily detectable in visible light and also display fluorescence when viewed under UV-A light or a combination visible and UV-A light. Refer to 8.5.5.

8.5.4 *Suspension Vehicles*—Generally the particles are suspended in a light petroleum (low-viscosity) distillate or conditioned water. (If sulfur or chlorine limits are specified, use Test Methods E165/E165M, Annex A2 or A4 to determine their values.

8.5.4.1 *Petroleum Distillates*—Low-viscosity light petroleum distillates vehicles (AMS 2641 Type 1 or equal) are ideal for suspending both fluorescent and nonfluorescent magnetic particles and are commonly employed.

(1) Advantages—Two significant advantages for the use of petroleum distillate vehicles are: (a) the magnetic particles are suspended and dispersed in petroleum distillate vehicles without the use of conditioning agents; and (b) the petroleum distillate vehicles provide a measure of corrosion protection to parts and the equipment used.

(2) Disadvantages—Principal disadvantages are flammability, fumes, and availability. It is essential, therefore, to select and maintain readily available sources of supply of petroleum distillate vehicles that have as high a flash point as practicable to avoid possible flammability problems and provide a work area with proper ventilation.

(3) Characteristics—Petroleum distillate vehicles to be used in wet magnetic particle testing should possess the following: (*a*) viscosity should not exceed 3.0 cSt (3 mm^2/s) at 100°F (38°C) and not more than 5.0 cSt (5 mm^2/s) at the lowest temperature at which the vehicle will be used; when verified in accordance with Test Method D445, in order not to impede particle mobility (see 20.7.3), (*b*) minimum flash point, when verified in accordance with Test Methods D93, should be 200°F (93°C) in order to minimize fire hazards (see 20.7.4), (*c*) odorless; not objectionable to user, (*d*) low inherent fluorescence if used with fluorescent particles; that is, it should not interfere significantly with the fluorescent particle indications (see 20.6.4.1), and (*e*) nonreactive; should not degrade suspended particles.

8.5.4.2 *Water Vehicles with Conditioning Agents*—Water may be used as a suspension vehicle for wet magnetic particles provided suitable conditioning agents are added which provide proper wet dispersing, in addition to corrosion protection for the parts being examined and the equipment in use. Plain water does not disperse some types of magnetic particles, does not wet all surfaces, and is corrosive to parts and equipment. On the other hand, conditioned water suspensions of magnetic particles are safer to use since they are nonflammable. The selection and concentration of the conditioning agent should be as recommended by the particle manufacturer. The following are recommended properties for water vehicles containing conditioning agents for use with wet magnetic particle testing:

(1) Wetting Characteristics—The vehicle should have good wetting characteristics; that is, wet the surface to be examined, give even, complete coverage without evidence of dewetting the examination surface. The surface tension (coverage) should be observed independently under both UV-A (black) light and visible light. Smooth examination surfaces require that a greater percentage of wetting agent be added than is required for rough surface. Nonionic wetting agents are recommended (see 20.7.5).

(2) Suspension Characteristics—Impart good dispersability; that is, thoroughly disperse the magnetic particles without evidence of particle agglomeration.

(3) Foaming—Minimize foaming; that is, it should not produce excessive foam which would interfere with indication formation or cause particles to form scum with the foam.

(4) Corrosiveness—It should not corrode parts to be examined or the equipment in which it is used.

(5) Viscosity Limit—The viscosity of the conditioned water should not exceed a maximum viscosity of 3 cSt (3 mm^2/s) at 100°F (38°C) (see 20.7.3).

(6) Fluorescence—The conditioned water should not produce excessive fluorescence if intended for use with fluorescent particles.

(7) Nonreactiveness—The conditioned water should not cause deterioration of the suspended magnetic particles.

(8) Water pH—The pH of the conditioned water should not be less than 7.0 or exceed 10.5.

(9) Odor—The conditioned water should be essentially odorless.

8.5.5 *Concentration of Wet Magnetic Particle Suspension*—The initial bath concentration of suspended magnetic particles should be as specified or as recommended by the manufacturer and should be checked by settling volume measurements and maintained at the specified concentration on a daily basis. If the concentration is not maintained properly, examination results can vary greatly. The concentration of dual response particles in the wet-method bath suspension may be adjusted to best perform in the desired lighting environment. Higher particle concentration is recommended for visible light areas and lower particle concentration is recommended for UV-A areas. Use in accordance with the particle manufacturer's recommendations.

8.5.6 *Application of Wet Magnetic Particles* (see 15.2).

8.5.7 *Magnetic Slurry/Paint Systems*—Another type of examination vehicle is the magnetic slurry/paint type consisting of a heavy oil in which flake-like particles are suspended. The material is normally applied by brush before the part is magnetized. Because of the high viscosity, the material does not rapidly run off surfaces, facilitating the examination of vertical or overhead surfaces. The vehicles may be combustible, but the fire hazard is very low. Other hazards are very similar to those of the oil and water vehicles previously described.

8.5.8 *Polymer-Based Systems*—The vehicle used in the magnetic polymer is basically a liquid polymer which disperses the magnetic particles and which cures to an elastic solid in a given period of time, forming fixed indications. Viscosity limits of standard wet technique vehicles do not apply. Care should be exercised in handling these polymer materials. Use in accordance with manufacturer's instructions and precautions. This technique is particularly applicable to examination areas of limited visual accessibility, such as bolt holes.

9. Part Preparation

9.1 *General*—The surface of the ferromagnetic part to be examined should be essentially clean, dry, and free of contaminants such as dirt, oil, grease, loose rust, loose mill sand, loose mill scale, lint, thick paint, welding flux/slag, and weld splatter that might restrict particle movement. See 15.1.2 about applying dry particles to a damp/wet surface. When examining a local area, such as a weld, the areas adjacent to the surface to be examined, as agreed by the contracting parties, must also be cleaned to the extent necessary to permit detection of indications. See Appendix X6 for more information on steels.

9.1.1 *Nonconductive Coatings*—Thin nonconductive coatings, such as paint in the order of 1 or 2 mil (0.02 to 0.05 mm) will not normally interfere with the formation of indications, but they must be removed at all points where electrical contact is to be made for direct magnetization. Indirect magnetization does not require electrical contact with the part/piece. See Section 12.2. If a nonconducting coating/plating is left on the area to be examined that has a thickness greater than 2 mil (0.05 mm), it must be demonstrated that unacceptable discontinuities can be detected through the maximum thickness applied.

9.1.2 *Conductive Coatings*—A conductive coating (such as chrome plating and heavy mill scale on wrought products resulting from hot forming operations) can mask discontinuities. As with nonconductive coatings, it must be demonstrated that the unacceptable discontinuities can be detected through the coating.

9.1.3 *Residual Magnetic Fields*—If the part/piece holds a residual magnetic field from a previous magnetization that will interfere with the examination, the part must be demagnetized. See Section 18.

9.2 *Cleaning Examination Surface*—Cleaning of the examination surface may be accomplished by detergents, organic solvents, or mechanical means. As-welded, as-rolled, as-cast, or as-forged surfaces are generally satisfactory, but if the surface is unusually nonuniform, as with burned-in sand, a very rough weld deposit, or scale, interpretation may be difficult because of mechanical entrapment of the magnetic particles. In case of doubt, any questionable area should be recleaned and reexamined (see 9.1).

9.2.1 *Plugging and Masking Small Holes and Openings*—Unless prohibited by the purchaser, small openings and oil holes leading to obscure passages or cavities can be plugged or masked with a suitable nonabrasive material which is readily removed. In the case of engine parts, the material must be soluble in oil. Effective masking must be used to protect components that may be damaged by contact with the particles or particle suspension.

10. Sequence of Operations

10.1 *Sequencing Particle Application and Establishing Magnetic Flux Field*—The sequence of operation in magnetic particle examination applies to the relationship between the timing and application of particles and establishing the magnetizing flux field. Two basic techniques apply, that is, continuous (see 10.1.1 and 10.1.2) and residual (see 10.1.3), both of which are commonly employed in industry.

10.1.1 *Continuous Magnetization*—Continuous magnetization is employed for most applications utilizing either dry or wet particles and will provide higher magnetic field strengths, to aid indication formation better, than residual magentic fields. The continuous method must be used when performing multidirectional magnetization. The sequence of operation for the dry and the wet continuous magnetization techniques are significantly different and are discussed separately in 10.1.1.1 and 10.1.1.2.

10.1.1.1 *Dry Continuous Magnetization Technique*—Unlike a wet suspension, dry particles lose most of their mobility when they contact the surface of a part. Therefore, it is imperative that the part/area of interest be under the influence of the applied magnetic field while the particles are still airborne and free to be attracted to leakage fields. This dictates that the flow of magnetizing current be initiated prior to the application of dry magnetic particles and terminated after the application of powder has been completed and any excess has been blown off. Magnetizing with HW current and AC current provide additional particle mobility on the surface of the part. Examination with dry particles is usually carried out in conjunction with prod-type or yoke localized magnetizations, and buildup of indications is observed as the particles are being applied.

10.1.1.2 *Wet Continuous Magnetization Technique*—The wet continuous magnetization technique involves bathing the part with the examination medium to provide an abundant source of suspended particles on the surface of the part and terminating the bath application immediately prior to the termination of the magnetizing current. The duration of the magnetizing current is typically on the order of ½ s for each magnetizing pulse (shot), with two or more shots given to the part. To insure that indications are not washed away, the subsequent shots should follow the first while the particles are still mobile on the surface of the part.

10.1.1.3 *Polymer or Slurry Continuous Magnetization Technique*—Prolonged or repeated periods of magnetization are often necessary for polymer- or slurry-base suspensions because of slower inherent magnetic particle mobility in the high-viscosity suspension vehicles.

10.1.2 *True Continuous Magnetization Technique*—In this technique, the magnetizing current is sustained throughout both the processing and examination of the part.

10.1.3 *Residual Magnetization Techniques:*

10.1.3.1 *Residual Magnetization*—In this technique, the examination medium is applied after the magnetizing force has been discontinued. It can be used only if the material being examined has relatively high retentivity so the residual leakage field will be of sufficient strength to attract and hold the particles and produce indications. This technique may be advantageous for integration with production or handling requirements or when higher than residual field strengths are not required to achieve satisfactory results. When inducing circular fields and longitudinal fields of long pieces, residual fields are normally sufficient to meet magnetizing requirements consistent with the requirements of Section 14. The residual method has found wide use examining pipe and tubular goods. For magnetization requirements of oilfield tubulars, refer to Appendix X8. Unless demonstrations with typical parts indicate that the residual field has sufficient strength to produce relevant indications of discontinuities (see 20.8) when the field is in proper orientation, the continuous method should be used.

11. Types of Magnetizing Currents

11.1 *Basic Current Types*—The four basic types of current used in magnetic particle testing to establish part magnetization are alternating current (AC), half-wave rectified current (HW), full-wave rectified current (FW), and for a special application, DC.

11.1.1 *Alternating Current (AC)*—Part magnetization with alternating current is preferred for those applications where examination requirements call for the detection of discontinuities, such as fatigue cracks, that are open to the surface to which the magnetizing force is applied. Associated with AC is a "skin effect" that confines the magnetic field at or near to the surface of a part. In contrast, both HW current and FW current produce a magnetic field having penetrating capabilities proportional to the amount of applied current, which should be used when near-surface or inside surface discontinuities are of concern.

11.1.2 *Half-Wave Rectified Current (HW)*—Half-wave current is frequently used in conjunction with wet and dry particles because the current pulses provide more mobility to the particles. This waveform is used with prods, yokes, mobile and bench units. Half-wave rectified current is used to achieve depth of penetration for detection of typical discontinuities found in weldments, forgings, and ferrous castings. As with AC for magnetization, single-phase current is utilized and the average value measured as "magnetizing current."

11.1.3 *Full-Wave Rectified Current (FW)*—Full-wave current may utilize single- or three-phase current. Three-phase current has the advantage of lower line amperage draws, whereas single-phase equipment is less expensive. Full-wave rectified current is commonly used when the residual method is to be employed. Because particle movement, either dry or wet is noticeably less, precautions must be taken to ensure that sufficient time is allowed for formation of indications.

11.1.4 *Direct Current (DC)*—A bank of batteries, full-wave rectified AC filtered through capacitors or a DC generator produce direct magnetizing current. They have largely given way to half-wave rectified or full-wave rectified DC except for a few specialized applications, primarily because of broad application advantages when using other types of equipment.

11.1.5 *Capacitor Discharge (CD) Current*—A bank of capacitors are used to store energy and when triggered the energy reaches high amperage with a very short duration (normally less than 25 milliseconds). Because of the short pulse duration the current requirements are affected by the amount of material to be magnetized as well as the applied amperage. The capacitor discharge technique is widely used to establish a residual magnetic field in tubing, casing, line pipe, and drill pipe. For specific requirements, see Appendix X8.

12. Part Magnetization Techniques

12.1 *Examination Coverage*—All examinations should be conducted with sufficient area overlap to assure the required coverage at the specified sensitivity has been obtained.

12.2 *Direct and Indirect Magnetization*—A part can be magnetized either directly or indirectly. For direct magnetization the magnetizing current is passed directly through the part creating a magnetic field oriented 90 degrees to current flow in the part. With indirect magnetization techniques a magnetic field is induced in the part, which can create a circular/toroidal, longitudinal, or multidirectional magnetic field in the part. The techniques described in 20.8 for verifying that the magnetic fields have the anticipated direction and strength should be employed. This is especially important when using multidirectional techniques to examine complex shapes.

12.3 *Choosing Magnetization Technique*—The choice of direct or indirect magnetization will depend on such factors as size, configuration, or ease of processing. Table 1 compares the advantages and limitations of the various methods of part magnetization.

TABLE 1 Advantages and Limitations of the Various Ways of Magnetizing a Part

Magnetizing Technique and Material Form	Advantages	Limitations
I. Direct Contact Part Magnetization (see 12.3.1)		
Head/Tailstock Contact		
Solid, relatively small parts (castings, forgings, machined pieces) that can be processed on a horizontal wet unit	1. Fast, easy technique.	1. Possibility of arc burns if poor contact conditions exist.
	2. Circular magnetic field surrounds current path.	2. Long parts should be examined in sections to facilitate bath application without resorting to an overly long current shot.
	3. Good sensitivity to surface and near-surface discontinuities.	
	4. Simple as well as relatively complex parts can usually be easily processed with one or more shots.	
	5. Complete magnetic path is conducive to maximizing residual characteristics of material.	
Large castings and forgings	1. Large surface areas can be processed and examined in relatively short time.	1. High amperage requirements (16 000 to 20 000 A) dictate costly DC power supply.
Cylindrical parts such as tubing, pipe, hollow shafts, etc.	1. Entire length can be circularly magnetized by contacting, end to end.	1. Effective field limited to outside surface and cannot be used for inside diameter examination.

TABLE 1 *Continued*

Magnetizing Technique and Material Form	Advantages	Limitations
		2. Ends must be conductive to electrical contacts and capable of carrying required current without excessive heat. Cannot be used on oilfield tubulars because of possibility of arc burns.
Long solid parts such as billets, bars, shafts, etc.	1. Entire length can be circularly magnetized by contacting, end to end.	1. Output voltage requirements increase as the part length increases, due to greater value of the impedance and/or resistance as the cables and part length grows.
	2. Current requirements are independent of length.	2. Ends must be conductive to electrical contact and capable of carrying required current without excessive heat.
	3. No end loss.	
Prods: Welds	1. Circular field can be selectively directed to weld area by prod placement.	1. Only small area can be examined at one time.
	2. In conjunction with half-wave rectified alternating current and dry powder, provides excellent sensitivity to subsurface discontinuities as well as surface type.	2. Arc burns due to poor contact.
	3. Flexible, in that prods, cables, and power packs can be brought to examination site.	3. Surface must be dry when dry powder is being used.
		4. Prod spacing must be in accordance with the magnetizing current level.
Large castings or forgings	1. Entire surface area can be examined in small increments using nominal current values.	1. Coverage of large surface area require a multiplicity of shots that can be very time-consuming.
	2. Circular field can be concentrated in specific areas that historically are prone to discontinuities.	2. Possibility of arc burns due to poor contact. Surface should be dry when dry powder is being used.
	3. Equipment can be brought to the location of parts that are difficult to move.	3. Large power packs (over 6000A) often require a large capacity voltage source to operate.
	4. In conjunction with half-wave rectified alternating current and dry powder, provides excellent sensitivity to near surface subsurface type discontinuities that are difficult to locate by other methods.	4. When using HW current or FW current on retentive materials, it is often necessary that the power pack be equipped with a reversing DC demagnetizing option.
II. Indirect Part Magnetization (see 12.3.2)		
Central Conductor		
Miscellaneous parts having holes through which a conductor can be placed such as: Bearing race Hollow cylinder Gear Large nut	1. When used properly, no electrical contact is made with the part and possibility of arc burns eliminated.	1. Size of conductor must be ample to carry required current.
	2. Circumferentially directed magnetic field is generated in all surfaces, surrounding the conductor (inside diameter, faces, etc.).	2. Larger diameters require repeated magnetization with conductor against inside diameter and rotation of part between processes. Where continuous magnetization technique is being employed, examination is required after each magnetization step.
	3. Ideal for those cases where the residual method is applicable.	
	4. Light weight parts can be supported by the central conductor.	
	5. Smaller central conductor and multiple coil wraps may be used to reduce current requirements.	
Large clevis Pipe coupling, casing/tubing		
Tubular type parts such as: Pipe/Casting Tubing Hollow shaft	1. When used properly, no electrical contact is made with the part and possibility of arc burns eliminated.	1. Outside surface sensitivity may be somewhat less than that obtained on the inside surface for large diameter and extremely heavy wall sections.
	2. Inside diameter as well as outside diameter examination.	
	3. Entire length of part circularly magnetized.	
Large valve bodies and similar parts	1. Provides good sensitivity for detection of discontinuities located on internal surfaces.	1. Outside surface sensitivity may be somewhat less than that obtained on the inside diameter for heavy wall sections.
Coil/Cable Wrap Miscellaneous medium-sized parts where the length predominates such as a crankshaft	1. All generally longitudinal surfaces are longitudinally magnetized to effectively locate transverse discontinuities.	1. Length may dictate multiple shot as coil is repositioned.
		2. Longitudinal magnetization of complex parts with upsets such as crankshafts will lead to dead spots where the magnetic field is cancelled out. Care must be taken to assure magnetization of all areas in perpendicular directions.
Large castings, forgings, or shafting	1. Longitudinal field easily attained by means of cable wrapping.	1. Multiple magnetization may be required due to configuration of part.
Miscellaneous small parts	1. Easy and fast, especially where residual magnetization is applicable.	1. L/D (length/diameter) ratio important consideration in determining adequacy of ampere-turns.

TABLE 1 *Continued*

Magnetizing Technique and Material Form	Advantages	Limitations
	2. No electrical contact.	2. Effective L/D ratio can be altered by utilizing pieces of similar cross-sectional area.
	3. Relatively complex parts can usually be processed with same ease as those with simple cross section.	3. Use smaller coil for more intense field.
		4. Sensitivity diminishes at ends of part due to general leakage field pattern.
		5. Quick break desirable to minimize end effect on short parts with low L/D ratio.
Induced Current Fixtures		
Examination of ring-shaped part for circumferential-type discontinuities.	1. No electrical contact.	1. Laminated core required through ring.
	2. All surface of part subjected to toroidal-type mag- netic field.	2. Type of magnetizing current must be compatible with method.
	3. Single process for 100 % coverage.	3. Other conductors encircling field must be avoided.
	4. Can be automated.	4. Large diameters require special consideration.
Ball examination	1. No electrical contact.	1. For small-diameter balls, limited to residual magnetization.
	2. 100 % coverage for discontinuities in any direction with three-step process and proper orientation between steps.	
	3. Can be automated.	
Disks and gears	1. No electrical contact.	1. 100 % coverage may require two-step process with core or pole-piece variation, or both.
	2. Good sensitivity at or near periphery or rim.	2. Type of magnetizing current must be compatible with part geometry.
	3. Sensitivity in various areas can be varied by core or pole-piece selection.	
Yokes:		
Examination of large surface areas for surface-type discontinuities.	1. No electrical contact.	1. Time consuming.
	2. Highly portable.	2. Must be systematically repositioned in view of random discontinuity orientation.
	3. Can locate discontinuities in any direction with proper orientation.	
Miscellaneous parts requiring examination of localized areas.	1. No electrical contact.	1. Must be properly positioned relative to orientation of discontinuities.
	2. Good sensitivity to direct surface discontinuities.	2. Relatively good contact must be established between part and poles.
	3. Highly portable.	3. Complex part geometry may cause difficulty.
	4. Wet or dry technique.	4. Poor sensitivity to subsurface-type discontinuities except in isolated areas.
	5. Alternating-current type can also serve as demagnetizer in some instances.	

12.3.1 *Direct Contact Magnetization*—For direct magnetization, physical contact must be made between the ferromagnetic part and the current carrying electrodes connected to the power source. Both localized area magnetization and overall part magnetization are direct contact means of part magnetization, and can be achieved through the use of prods, head and tailstock, clamps, and magnetic leeches.

12.3.2 *Localized Area Magnetization:*

12.3.2.1 *Prod Technique*—The prod electrodes are first pressed firmly against the part under examination (see Fig. 2). The magnetizing current is then passed through the prods and into the area of the part in contact with the prods. This establishes a circular magnetic field in the part around and between each prod electrode, sufficient to carry out a local magnetic particle examination (see Fig. 2). (**Warning—** Extreme care should be taken to maintain clean prod tips, to minimize heating at the point of contact and to prevent arc burns and local overheating on the surface being examined since these may cause adverse effects on material properties. Arc burns may cause metallurgical damage; if the tips are solid copper, copper penetration into the part may occur. Prods should not be used on machined surfaces or on aerospace component parts.)

(1) Unrectified AC limits the prod technique to the detection of surface discontinuities. Half-wave rectified AC is most desirable since it will detect both surface and near-surface discontinuities. The prod technique generally utilizes dry magnetic particle materials due to better particle mobility. Wet magnetic particles are not generally used with the prod technique because of potential electrical and flammability hazards.

(2) Proper prod examination requires a second placement with the prods rotated approximately 90° from the first placement to assure that all existing discontinuities are revealed. Depending on the surface coverage requirements, overlap between successive prod placements may be necessary. On large surfaces, it is good practice to layout a grid for prod/yoke placement.

12.3.2.2 *Manual Clamp/Magnetic Leech Technique*—Local areas of complex components may be magnetized by electrical contacts manually clamped or attached with magnetic leeches to the part (Fig. 5). As with prods, sufficient overlap may be necessary if examination of the contact location is required.

12.3.2.3 *Overall Magnetization:* (*1*) *Head and Tailstock Contact*—Parts may be clamped between two electrodes (such as a head and tailstock of horizontal wet magnetic particle

FIG. 5 Direct Contact Magnetization through Magnetic Leech Clamp of Part

equipment) and the magnetizing current applied directly through the part (Fig. 6). The size and shape of the part will determine whether both field directions can be obtained with such equipment.

(*2*) *Clamps*—The magnetizing current may be applied to the part under examination by clamping (Fig. 7) the current carrying electrodes to the part, producing a circular magnetic field.

FIG. 7 Spring Loaded Contact Clamp

(*3*) *Multidirectional Magnetization Technique*—With suitable circuitry, it is possible to produce a multidirectional (oscillating) field in a part by selectively switching the magnetic field within the part between electrode contacts/clamps positioned approximately 90° apart or by using a combination of switched direct and indirect methods, such as contact and coil. This permits building up indications in all possible directions and may be considered the equivalent of magnetizing in two or more directions (Fig. 8). On some complex shapes as many as 16 to 20 steps may be required with conventional equipment. With multidirectional magnetization, it is usually possible to reduce the magnetizing steps required by more than half. In many instances, the number of steps may be reduced to one. It is essential that the wet continuous method, be used and that the magnetic field direction and relative intensity be determined by AS 5371 shims as described in Appendix X2 or with an identical part with discontinuities in all areas of interest.

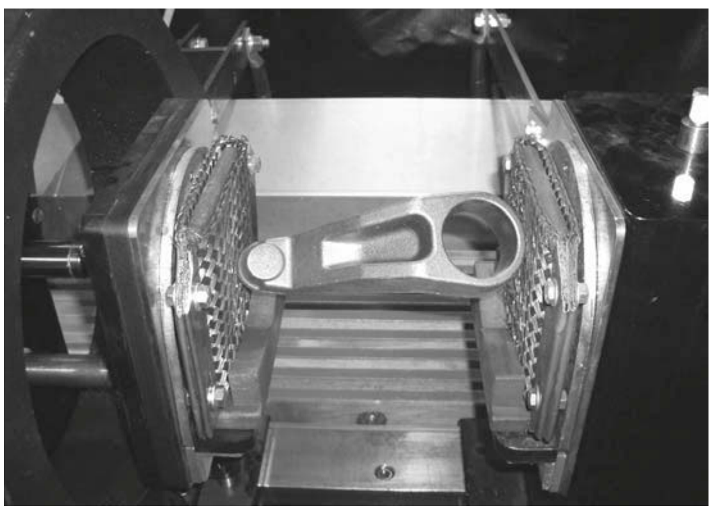


FIG. 6 Direct Contact Shot

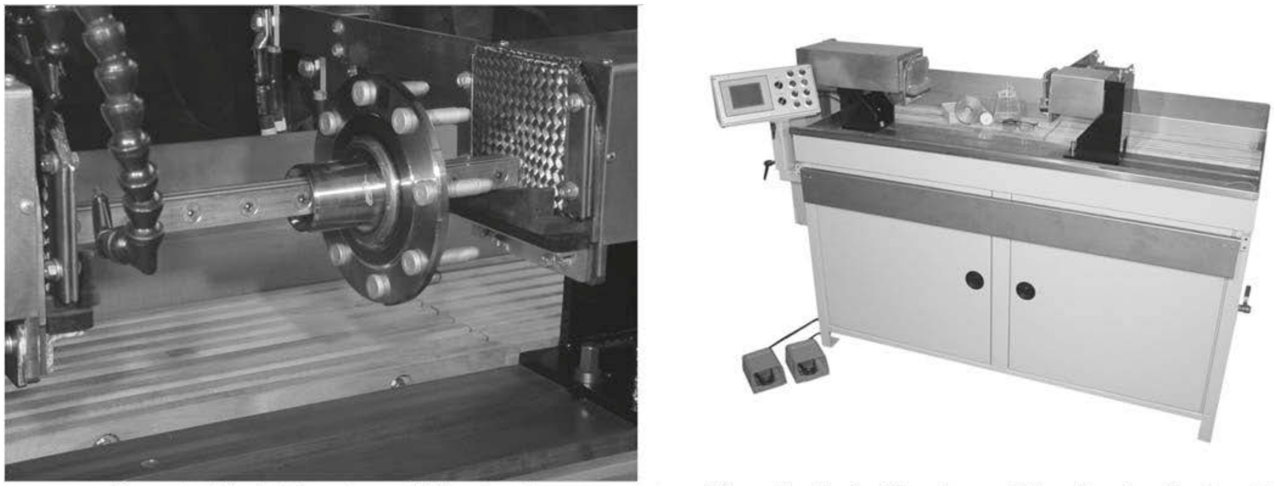


Figure A - Typical 2-vector multidirectional wet horizontal using laminated core

Figure B - Typical 2-vector multidirectional wet horizontal

FIG. 8 Multidirectional Magnetic Particle Units

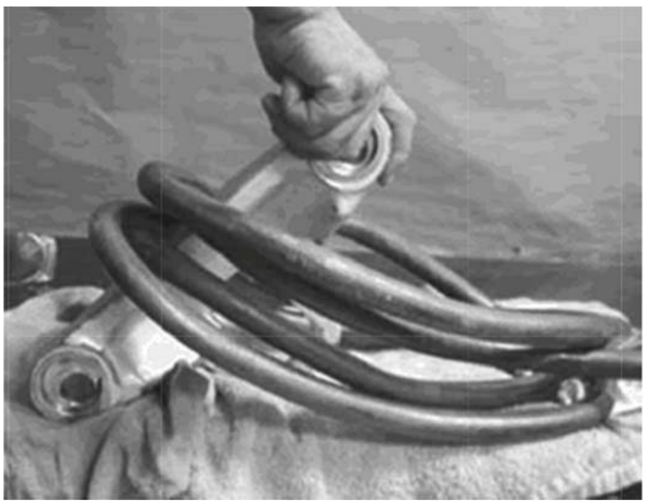


FIG. 9 Cable Wrap Magnetization Examples (9a – Low Fill Factor Example)

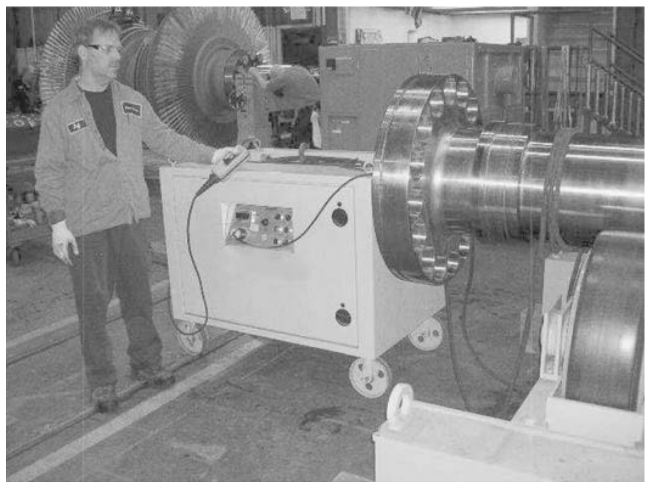


FIG. 9 Cable Wrap Magnetization Examples (9b – High Fill Factor Example) *(continued)*

12.3.3 *Indirect Magnetization*—Indirect part magnetization involves the use of a preformed coil, cable wrap, yoke, or a central conductor to induce a magnetic field. Coil, cable wrap, and yoke magnetization are referred to as longitudinal magnetization in the part (see 13.4).

12.3.3.1 *Coil and Cable Magnetization*—When coil (Fig. 4) or cable wrap (Fig. 9a and b) techniques are used, the magnetizing force is proportional to ampere turns (see X3.2.2).

12.3.3.2 *Central Conductor, Induced Current Magnetization*—Indirect circular magnetization of hollow pieces/parts can be performed by passing the magnetizing current through a central conductor (Fig. 10(a) and Fig. 10(b)) or cable used as a central conductor or through an induced current fixture (Fig. 8(A)). Central conductors may be solid or hollow and are ideally made from non-ferrous material. Ferrous central conductors will function as well, but will generate substantial heat due to magnetic domain movement and a reduced magnetic field outside the conductor when compared to a non-ferrous conductor. Additionally, when using ferromagnetic conductors, the inspector must be made aware of the possibility of magnetic writing. When using central conductors, the distance along the part circumference, which may be effectively examined should be taken as approximately four times the diameter of the central conductor, as illustrated in Fig. 10 (b). The presence of suitable fields in the effective region of examination should be verified. The entire circumference should be examined by rotating the part on the conductor, allowing for approximately a 10 % magnetic field overlap. Central conductors are widely used in magnetic particle examination to provide:

(1) A circular field on both the inside surface and outside surface of tubular pieces that cannot be duplicated by the direct current technique.

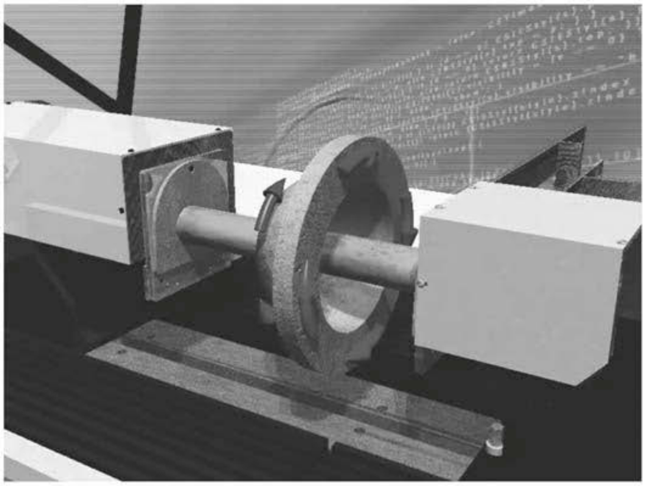


Figure A

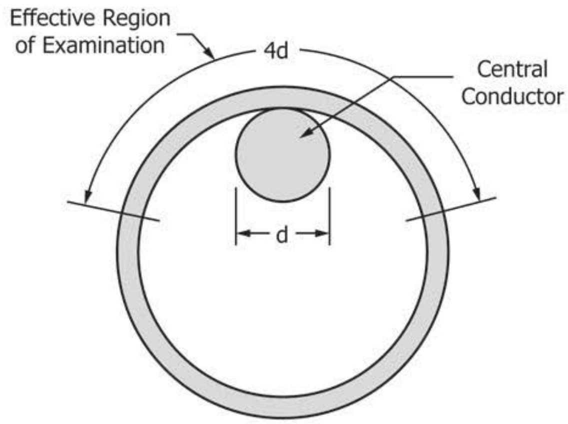


Figure B

FIG. 10 Central Bar Conductors

(2) A non-contact means of part magnetization virtually eliminating the possibility of arc burning the material, as can be the case with current flow through contacts, such as prods or clamps.

(3) Substantial processing advantages over direct contact techniques on ring-shaped parts.

(4) In general it is not important for the central conductor to be centered because the flux lines follow the path of least resistance through the ferromagnetic material. On large diameter materials the central conductor should be within 6 in. of the center. The resulting field is concentric relative to the axis of the piece and is maximum at the inside surface.

12.3.3.3 *Yoke Magnetization*—A magnetic field can be induced into a part by means of an electromagnet (see Fig. 1), where the part or a portion thereof becomes the magnetic path between the poles (acts as a keeper) and discontinuities preferentially transverse to the alignment of the pole pieces are indicated. Most yokes are energized by an input of AC and produce a magnetizing field of AC, half-wave DC, or full-wave DC. A permanent magnet can also introduce a magnetic field in the part, but its use is restricted (see 6.3.1).

13. Direction of Magnetic Fields

13.1 *Discontinuity Orientation vs. Magnetic Field Direction*—Since indications are not normally obtained when discontinuities are parallel to the magnetic field, and since indications may occur in various or unknown directions in a part, each part must be magnetized in at least two directions approximately at right angles to each other as noted in 4.3.2. On some parts circular magnetization may be used in two or more directions, while on others both circular and longitudinal magnetization are used to achieve the same result. For purposes of demagnetization verification, circular magnetism normally precedes longitudinal magnetization. A multidirectional field can also be employed to achieve part magnetization in more than one direction.

13.2 *Circular Magnetization*—Circular magnetization (Fig. 11) is the term used when electric current is passed through a part, or by use of a central conductor (see 12.3.3.2) through a central opening in the part, inducing a magnetic field at right angles to the current flow. Circular fields normally produce strong residual fields, but are not measurable because the flux is contained within the part.

FIG. 11 Circular Magnetism

13.3 *Transverse Magnetization*—Transverse magnetization is the term used when the magnetic field is established across the part and the lines of flux complete their loop outside the part. Placing a yoke across a bar normal to the bar axis would produce a transverse field.

13.4 *Toroidal Magnetization*—When magnetizing a part with a toroidal shape, such as a solid wheel or the disk with a center opening, an induced field that is radial to the disk is most useful for the detection of discontinuities in a circumferential direction. In such applications this field may be more effective than multiple shots across the periphery, but requires special equipment.

13.5 *Longitudinal Magnetization*—Longitudinal magnetization (Fig. 12) is the term used when a magnetic field is

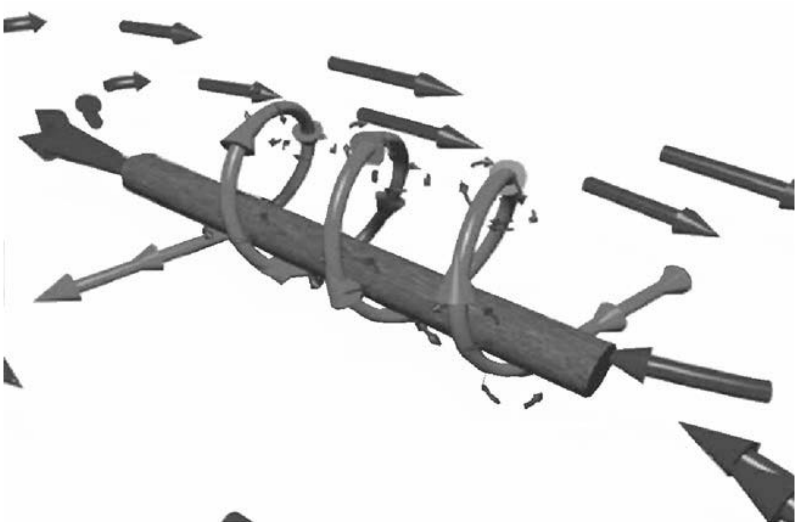


FIG. 12 Longitudinal Magnetism

generated by an electric current passing through a multiturn, which encloses the part or section of the part to be examined.

13.6 *Multidirectional Magnetization*—Multidirectional magnetization may be used to fulfill the requirement for magnetization in two directions if it is demonstrated that it is effective in all areas of interest. Examine parts in accordance with 20.8.2 or shims manufactured to the requirements of AS 5371 (see Appendix X2), or as otherwise approved by the Level 3 and the Cognizant Engineering Organization, may be used to verify field direction, strength, and balance in multidirectional magnetization. Balance of the field intensity is critical. The field intensity should be balanced in all directions. The particle application must be timed so that the magnetization levels reach full value in all directions, while the particles are mobile on the surface under examination.

13.6.1 When actual parts with known defects are used, the number and orientation(s) of the defects (for example, axial, longitudinal, circumferential, etc.) should be noted. The magnetic field intensity can be considered as being properly balanced when all noted defects can be readily identified with particle indications.

13.7 *Flexible Laminated Strips for Magnetic Particle Testing*

13.7.1 Flexible laminated strips as described in Appendix X1 may be used to ensure proper field direction during magnetic particle examination. The longitudinal axis of the strip should be placed perpendicular to the direction of the magnetic field of interest in order to generate the strongest particle indications on the strip. Flexible laminated strips may only be used as a tool to demonstrate the direction of the external magnetic field.

14. Magnetic Field Strength

14.1 *Magnetizing Field Strengths*—To produce interpretable indications, the magnetic field in the part must have sufficient strength and proper orientation. For the indications to be consistent, this field strength must be controlled within reasonable limits, usually ±25 % on single vector equipment and when using multi-directional equipment, the field strength must be controlled much closer, often within ±5 %. Factors that affect the strength of the field are the size, shape, section thickness, material of the part/piece, and the technique of magnetization. Since these factors vary widely, it is difficult to establish rigid rules for magnetic field strengths for every conceivable configuration.

14.2 *Establishing Field Strengths*—Sufficient magnetic field strength can be established by:

14.2.1 *Known Discontinuities*—Experiments with similar/identical parts having known discontinuities in all areas of interest.

14.2.2 *Artificial Discontinuities*—Verification of indications derived from AS 5371 shims (see Appendix X2) taped or glued defect side in contact with the part under examination is an effective means of verifying field strength when using the continuous method.

14.2.3 *Hall-effect Meter Tangential Field Strengths*—A minimum tangential applied field strength of 30 G (2.4 kAM^{-1}) should be adequate when using single vector equipment. Stronger field strengths are allowed, but it must not be so strong that it causes the masking of relevant indications by nonrelevant accumulations of magnetic particles. Due to the complex number of variables, the use of Gaussmeters should not be the sole source of determining an acceptable field on multi-directional techniques.

14.2.3.1 *Circular Magnetism Hall-effect Meter Measurement*—On a part with consistent diameter or thickness, the transverse probe may be placed anywhere along the length of the part as the tangential circular field is consistent across the length. The transverse probe should be positioned upright such that the circular field is normal to the major dimension of the Hall-effect sensor and within 5° of perpendicularity to the part. More than one measurement should be taken to ensure consistent readings. On parts with more than one diameter/thickness, multiple measurements should be taken to ensure a minimum measurement of 30 gauss on all areas to be examined. Measurement is made of the applied field, that is, during the magnetizing shot, not the residual flux field.

14.2.3.2 *Longitudinal Magnetism Hall-effect Meter Measurement*—On a part with consistent diameter or thickness, the probe may be placed anywhere along the length of the part, except near the poles as the tangential longitudinal field is consistent across the length, except at the poles. Measurement near the poles will yield a skewed reading due to detection of the normal flux field at each pole. Also, measurement near any geometry change that would produce a non-relevant flux leakage should be avoided. The probe should be positioned within 5° of perpendicularity to the part and such that the longitudinal field is normal to the major dimension of the Hall-effect sensor. More than one measurement should be taken to ensure consistent readings. The Hall-effect probe may be placed within the coil or outside the vicinity of the coil if the part is longer than the width of the coil. On parts with more than one diameter/thickness, multiple measurements should be taken to ensure a minimum measurement of 30 gauss on all areas to be examined. Measurement is made of the applied field, that is, during the magnetizing shot, not the residual flux field.

14.2.4 *Using Empirical Formulas*—Appendix X3 details the use of empirical formulas for determining field strength. Amperages derived from empirical formulas should be verified with a Hall-effect gaussmeter or AS 5371 shims.

14.3 *Localized Magnetization:*

14.3.1 *Using Prods*—When using prods on material ¾ in. (19 mm) in thickness or less, it is recommended to use 90 to 115 A/in. of prod spacing (3.5 to 4.5 A/mm). For material greater than ¾ in. (19 mm) in thickness, it is recommended to use 100 to 125 A/in. of prod spacing. Prod spacing is recommended to be not less than 2 in. (50 mm) or greater than 8 in. (200 mm). The effective width of the magnetizing field when using prods is one fourth of the prod spacing on each side of a line through the prod centers.

14.3.2 *Using Yokes*—The field strength of a yoke (or a permanent magnet) can be empirically determined by measuring its lifting power (see 20.3.7). If a Hall-effect probe is used, it shall be placed on the surface midway between the poles.

15. Application of Dry and Wet Magnetic Particles

15.1 *Dry Magnetic Particles:*

15.1.1 *Magnetic Fields for Dry Particles*—Dry magnetic powders are generally applied with the continuous magnetizing techniques. When utilizing AC, the current must be on before application of the dry powder and remain on through the examination phase. With Half-wave rectified AC or yoke DC magnetization, a current duration of at least ½ s should be used. The current duration should be short enough to prevent any damage from overheating or from other causes. It should be noted that AC and half-wave rectified DC impart better particle mobility to the powder than DC or full-wave rectified AC. Dry magnetic powders are widely used for magnetic particle examination of large parts as well as on localized areas such as welds. Dry magnetic particles are widely used for oil field applications and are frequently used in conjunction with capacitor discharge style equipment and the residual method.

15.1.2 *Dry Powder Application*—It is recommended that dry powders be applied in such a manner that a light uniform, dust-like coating settles upon the surface of the part/piece while it is being magnetized. Dry particles must not be applied to a damp surface; they will have limited mobility. Neither should they be applied where there is excessive wind. The preferred application technique suspends the particles in air in such a manner that they reach the part surface being magnetized in a uniform cloud with a minimum of force. Usually, specially designed powder blowers and hand powder applicators are employed (see Fig. 1). Dry particles should not be applied by pouring, throwing, or spreading with the fingers.

15.1.3 *Excess Powder Removal*—Care is needed in both the application and removal of excess dry powder. Removal of excess powder is generally done while the magnetizing current is present and care must be exercised to prevent the removal of particles attracted by a leakage field, which may prove to be a relevant indication.

15.1.4 *Near-surface Discontinuities Powder Patterns*—In order to recognize the broad, fuzzy, weakly held powder patterns produced by near-surface discontinuities, it is essential to observe carefully the formation of indications while the powder is being applied and also while the excess is being removed. Sufficient time for indication formation and examination should be allowed between successive magnetization cycles.

15.2 *Wet Particle Application*—Wet magnetic particles, fluorescent or nonfluorescent, suspended in a vehicle at a recommended concentration may be applied either by spraying or flowing over the areas to be examined during the application of the magnetizing field current (continuous technique) or after turning off the current (residual technique). Proper sequencing of operation (part magnetization and timing of bath application) is essential to indication formation and retention. For the continuous technique multiple current shots should be applied. The last shot should be applied after the particle flow has been diverted and while the particle bath is still on the part. A single shot may be sufficient. Care should be taken to prevent damage to a part due to overheating or other causes. Since fine or weakly held indications on highly finished or polished surfaces may be washed away or obliterated, care must be taken to prevent high-velocity flow over critical surfaces and to cut off the bath application before removing the magnetizing force. Discontinuity detection may benefit from an extended drain time of several seconds before actual examination.

15.3 *Magnetic Slurry/Paints*—Magnetic slurry/paints are applied to the part with a brush before or during part magnetization. Indications appear as a dark line against a light silvery background. Magnetic slurry is ideal for overhead or underwater magnetic particle examination.

15.4 *Magnetic Polymers*—Magnetic polymers are applied to the part to be examined as a liquid polymer suspension. The part is then magnetized, the polymer is allowed to cure, and the elastic coating is removed from the examination surface for interpretation and evaluation. Care must be exercised to ensure that magnetization is completed within the active migration period of the polymer which is usually about 10 min. This method is particularly applicable to areas of limited visual access such as bolt holes. Detailed application and use instructions of the manufacturer should be followed for optimum results.

15.5 *White Background and Black Oxide*—A thin white background is applied by aerosol to provide a thin (≤ 2 mil), smooth, high contrast background prior to magnetization and particle application. After background has dried, magnetization and particle application follow normal procedures. The high contrast between the white background and black particles provides high sensitivity in visible light conditions. Detailed application and use instructions of the manufacturer should be followed for optimum results.

16. Interpretation of Indications

16.1 *Valid Indications*—All valid indications formed by magnetic particle examination are the result of magnetic leakage fields. Indications may be relevant (16.1.1), nonrelevant (16.1.2), or false (16.1.3).

16.1.1 *Relevant Indications*—Relevant indications are produced by leakage fields which are the result of discontinuities. Relevant indications require evaluation with regard to the acceptance standards agreed upon between the manufacturer/test agency and the purchaser (see Annex A1).

16.1.2 *Nonrelevant Indications*—Nonrelevant indications can occur singly or in patterns as a result of leakage fields created by conditions that require no evaluation such as changes in section (like keyways and drilled holes), inherent material properties (like the edge of a bimetallic weld), magnetic writing, etc.

16.1.3 *False Indications*—False indications are not the result of magnetic forces. Examples are particles held mechanically or by gravity in shallow depressions or particles held by rust or scale on the surface.

17. Recording of Indications

17.1 *Means of Recording*—When required by a written procedure, permanent records of the location, type, direction, length(s), and spacing(s) of indications may be made by one or more of the following means.

17.1.1 *Sketches*—Sketching the indication(s) and their locations.

17.1.2 *Transfer (Dry Powder Only)*—Covering the indication(s) with transparent adhesive-backed tape, removing the tape with the magnetic particle indication(s) adhering to it, and placing it on paper or other appropriate background material indicating locations.

17.1.3 *Strippable Film (Dry Powder Only)*—Covering the indication(s) with a spray-on strippable film that fixes the indication(s) in place. When the film is stripped from the part, the magnetic particle indication(s) adhere to it.

17.1.4 *Photographing*—Photographing the indications themselves, the tape, or the strippable film reproductions of the indications.

17.1.5 *Written Records*—Recording the location, length, orientation, and number of indications.

17.1.5.1 *Defect or Indication Sizing Accuracy*—For situations where defect or indication size limits are specified by the acceptance criteria, measurement equipment should be selected with an accuracy being precise enough to determine compliance. For example, to verify maximum defect length does not exceed 0.150 in. (3.81 mm) a measuring device accurate to ±0.010 in. (0.254 mm) could be used by reducing the allowable limit too 0.140 in. (3.56 mm), but using a measuring device accurate to ±0.150 in. (3.81 mm) or one with 0.100 in. (2.54 mm) increments is not accurate enough.

17.1.5.2 For situations where no defect or indication tolerances are specified (for example, reporting the length of a crack when the acceptance criteria is "No cracks allowed") the crack length should not be reported with more precision than the resolution of the measurement equipment allows. For example, when using a measuring device accurate to ±0.010 in. (0.254 mm) report the crack length in 0.010 in. (0.254 mm) increments.

17.1.5.3 Some contracts may require better than the minimum measurement accuracy needed to determine compliance. These situations are generally limited to critical direct measurement of deliverable product features, rather than examination parameter checks. For example, an accuracy ratio of 2 to 1 may be specified for measurement of defects or product geometry, which means an instrument with a calibrated accuracy of ±0.005 in. (0.127 mm) would be needed for verifying or reporting dimensions to the nearest ±0.010 in. (0.254 mm).

17.2 *Accompanying Information*—A record of the procedure parameters listed below as applicable should accompany the examination results:

17.2.1 *Method Used*—Magnetic particle method (dry, wet, fluorescent, etc.).

17.2.2 *Magnetizing Technique*—Magnetizing technique (continuous, true-continuous, residual).

17.2.3 *Current Type*—Magnetizing current (AC, half-wave rectified or full-wave rectified AC, etc.).

17.2.4 *Field Direction*—Direction of magnetic field (prod placement, cable wrap sequence, etc.).

17.2.5 *Field Strength*—Magnetic current strength (ampere turns, amperes per inch (millimetre) of prod spacing, lifting force, etc.).

18. Demagnetization

18.1 *Applicability*—All ferromagnetic material will retain some residual magnetism, the strength of which is dependent on the retentivity of the part. Residual magnetism does not affect the mechanical properties of the part. However, a residual field may cause chips, filing, scale, etc. to adhere to the surface affecting subsequent machining operations, painting, or plating. Additionally, if the part will be used in locations near sensitive instruments, high residual fields could affect the operation of these instruments. Furthermore, a strong residual magnetic field in a part to be welded or electroplated could interfere with welding or plating process. Residual fields may also interfere with later magnetic particle examination. Demagnetization is required only if specified in the drawings, specification, or purchase order. When required, an acceptable level of residual magnetization and the measuring method should also be specified. See 18.3.

18.2 *Demagnetization Methods*—The ease of demagnetization is dependent on the coercive force of the metal. High retentivity is not necessarily related to high coercive force in that the strength of the residual field is not always an indicator of ease of demagnetizing. In general, demagnetization is accomplished by subjecting the part to a field equal to or greater than that used to magnetize the part and in nearly the same direction, then continuously reversing the field direction while gradually decreasing it to zero.

18.2.1 *Withdrawal from Alternating Current Coil*—The fastest and most simple technique is to pass the part through a high intensity alternating current coil and then slowly withdraw the part from the field of the coil. A coil of 5000 to 10,000 ampere turns is recommended. Line frequency is usually from 50 to 60 Hz alternating current. The piece should enter the coil from a 12-in. (300-mm) distance and move through it steadily and slowly until the piece is at least 36 in. (900 mm) beyond the coil. Care should be exercised to ensure that the part is entirely removed from the influence of the coil before the demagnetizing force is discontinued, otherwise the demagnetizer may have the reverse effect and actually remagnetize the part. This should be repeated as necessary to reduce the residual field to an acceptable level. See 18.3. Small parts of complex figuration can be rotated and tumbled while passing through the field of the coil. Use of this technique may not be effective on large parts in which the alternating magnetic current field is insufficient to penetrate.

18.2.2 *Decreasing Alternating Current*—An alternative technique for part demagnetization is subjecting the part to the alternating magnetic field while gradually reducing its strength to a desired level.

18.2.3 *Demagnetizing with Yokes*—Alternating current yokes may be used for local demagnetization by placing the poles on the surface, moving them around the area, and slowly withdrawing the yoke while it is still energized.

18.2.4 *Reversing Direct Current*—The part to be demagnetized is subjected to consecutive steps of reversed and reduced direct current magnetization to a desired level. (This is the most effective process of demagnetizing large parts in which the alternating current field has insufficient penetration to remove the internal residual magnetization.) This technique requires special equipment for reversing the current while simultaneously reducing it in small increments.

18.3 *Extent of Demagnetization*—The effectiveness of the demagnetizing operation can be indicated by the use of appropriate magnetic field indicators. (**Warning—**A part may retain a strong residual field after having been circularly magnetized and exhibit little or no external evidence of this field. Therefore, the circular magnetization should be conducted before longitudinal magnetization if complete demagnetization is required. If a sacrificial part is available, in the case of a part such as a bearing race that has been circularly magnetized, it is often advisable to section one side of it and measure the remaining leakage field in order to check the demagnetizing process.)

18.3.1 After demagnetization, measurable residual fields should not exceed a value agreed upon or as specified on the engineering drawing or in the contract, purchase order, or specification.

19. Post Examination Cleaning

19.1 *Particle Removal*—Post-examination cleaning is necessary where magnetic particle material(s) could interfere with subsequent processing or with service requirements. Demagnetization should always precede particle removal. The purchaser should specify when post-examination cleaning is needed and the extent required.

19.2 *Means of Particle Removal*—Typical post-examination cleaning techniques employed are: (a) the use of compressed air to blow off unwanted dry magnetic particles; (b) drying of wet particles and subsequent removal by brushing or with compressed air; (c) removal of wet particles by flushing with solvent; and (d) other suitable post-examination cleaning techniques may be used if they will not interfere with subsequent requirements.

20. Process Controls

20.1 *Contributing Factors*—The overall performance of a magnetic particle testing system is dependent upon the following:

20.1.1 Operator capability, if a manual operation is involved.

20.1.2 Control of process steps.

20.1.3 The particles or suspension, or both.

20.1.4 The equipment.

20.1.5 Visible light level.

20.1.6 UV-A (black) light monitoring where applicable.

20.1.7 Magnetic field strength.

20.1.8 Field direction or orientation.

20.1.9 Residual field strength.

20.1.10 These factors should all be controlled individually.

20.2 *Maintenance and Calibration of Equipment*—The magnetic particle equipment employed should be maintained in proper working order at all times. The frequency of verification calibration, usually every six months, see Table 2, or whenever a malfunction is suspected, should be specified in the written procedures of the nondestructive testing facility. Records of the checks and results provide useful information for quality control purposes and should be maintained. In addition, any or all of the checks described should be performed whenever a malfunction of the system is suspected. Calibration checks should be conducted in accordance with the specifications or documents that are applicable.

20.2.1 *Equipment Calibration*—It is good practice that all calibrated equipment be traceable to the job it was used on. This facilitates possible re-examination or evaluation should a piece of equipment be found not working properly.

20.2.2 Some examination procedures may require equipment calibration or operational checks, but no accuracy requirement is specified, for that equipment, by the contractually specified magnetic particle examination procedure (for example, Practice E1444/E1444M light meters and gaussmeter accuracy), however the accuracy of the measuring device

TABLE 2 Recommended Verification Intervals

Item	Maximum Time Between Verifications[A]	Reference Paragraphs
Lighting:[B]		
Visible light intensity	weekly	7.1.1, 20.4.1
Ambient light intensity	weekly	7.1.1.2
UV-A light intensity	daily	7.1.2.1, 20.4.2
Battery powered UV-A light intensity check	before and after each use	6.6
UV-A light integrity	weekly	6.6, 20.4.2
System performance[B]	daily	20.8, Appendix X7
Wet particle concentration	8 h, or every shift change	20.6
Wet particle contamination[B]	weekly	20.6.4
Water break test	daily	20.7.5
Equipment calibration/check:[B]		
Ammeter accuracy	6 months	20.3.1
Timer control	6 months	20.3.2
Quick break	6 months	20.3.3
Yoke dead weight check	6 months	20.3.7
UV-A and white light meter checks	6 months	20.4
Gaussmeter or Field Indicator accuracy	6 months	20.3.6

[A]When the test system is in operation.
[B]The maximum time between verifications may be extended when substantiated by actual technical stability/reliability data.

should be reasonably suited for the situation with the resolution of the equipment being precise enough to determine compliance.

20.2.3 Equipment that meets an accuracy requirement specified by the contractually specified magnetic particle examination procedure (for example, Practice E1444/E1444M ammeter accuracy of ±10 % or 50 amperes, or a timer control ±0.1 second) should be considered adequate, with no additional accuracy or uncertainty determination needed.

20.2.4 Measurement equipment that the contractually specified magnetic particle inspection procedure does not specifically require to be calibrated or meet a specified accuracy (for example, timers, shop air pressure gauge, etc.) should be maintained in good working order and have measurement resolution reasonably suited for the intended use.

20.3 *Equipment Checks*—The following checks are recommended for ensuring the accuracy of magnetic particle magnetizing equipment.

20.3.1 *Ammeter Accuracy*—To check the equipment anmeter, a suitable and traceable calibrated shunt test kit shall be connected in series with the output circuit. Comparative readings should be taken at a minimum of three output levels encompassing the usable range of the equipment. The equipment meter reading should not deviate by more than ±10 % or 50 amperes, whichever is greater, from the current value shown by the calibrated ammeter. (When measuring half-wave rectified current, the current values shown by the calibrated FW-Rectified ammeter readings shall be doubled.) The frequency of the ammeter check is specified in Table 2. Machine output repeatability should not vary more than ±10 % or 50 amperes, whichever is greater, at any setpoint and the machine under test should be marked with the value representing the lowest repeatable current level.

20.3.2 *Timer Control Check*—On equipment utilizing a timer to control the duration of the current flow, the timer should be checked for accuracy as specified in Table 2 or whenever a malfunction is suspected. The timer should be calibrated to within ±0.1 seconds using a suitable electronic timer.

20.3.3 *Magnetic Field Quick Break Check*—On equipment that has a quick break feature, the functioning of this circuit should be checked and verified. This check may be performed using a suitable oscilloscope or a simple test device usually available from the manufacturer. Normally, only the fixed coil is checked for quick break functionality. Headstocks would need to be checked only if cables are attached to the headstocks to form a coil wrap. On electronic power packs or machines, failure to achieve indication of a "quick break" would indicate that a malfunction exists in the energizing circuit.

20.3.4 *Equipment Current Output Check*—To ensure the continued accuracy of the equipment, ammeter readings at each transformer tap should be made with a calibrated ammeter-shunt combination. This accessory is placed in series with the contacts. The equipment shunt should not be used to check the machine of which it is a part. For infinite current control units (non-tap switch), settings at 500-A intervals should be used. On uni-directional equipment, variations exceeding ±10 % from the equipment ammeter readings indicate the equipment needs service or repair. On multi-vector equipment, variations exceeding ±5 % from the equipment ammeter readings indicate the equipment needs service or repair.

20.3.5 *Internal Short Circuit Check*—Magnetic particle equipment should be checked periodically for internal short circuiting. With the headstocks set for maximum amperage output, any deflection of the ammeter when the current is activated with no conductor between the contacts is an indication of an internal short circuit and must be repaired prior to use.

20.3.6 *Hall-effect Meters*—Depending upon the manufacturer, meters are normally accurate for use with full-wave DC only. Hall-effect meter readings for HW and AC current applications should be correlated to the results of the application of AS 5371 shims. Hall-effect gaussmeters should be calibrated every six months in accordance with the manufacturer's instructions.

NOTE 3—When used with SCR controlled equipment, the Gaussmeter's accuracy is dependent upon the actual circuit design of each model meter and results may vary.

20.3.7 *Electromagnetic Yoke Lifting Force Check*—The magnetizing force of a yoke (or a permanent magnet) should be checked by determining its lifting power on a steel plate. See Table 3. The lifting force relates to the electromagnetic strength of the yoke.

20.3.8 *Powder Blower*—The performance of powder blowers used to apply the dry magnetic particles should be checked

TABLE 3 Minimum Yoke Lifting Force

Type Current	Yoke Pole Leg Spacing	
	2 to 4 in. (50 to 100 mm)	4 to 6 in. (100 to 150 mm)
AC	10 lb (45 N/4.5 kg)	
DC	30 lb (135 N/13.5 kg)	50 lb (225 N/23.0 kg)

at routine intervals or whenever a malfunction is suspected. The check should be made on a representative examination part. The blower should coat the area under evaluation with a light, uniform dust-like coating of dry magnetic particles and have sufficient force to remove the excess particles without disturbing those particles that are evidence of indications. Necessary adjustments to the blower's flow rate or air velocity should be made in accordance with the manufacturer's recommendations.

20.4 *Examination Area Light Level Control:*

20.4.1 *Visible Light Intensity*—Light intensity in the examination area should be checked at specified intervals with the designated light meter at the surface of the parts being examined. See Table 2.

20.4.2 *UV-A (Black) Light Intensity*—UV-A (black) light intensity should be checked at the specified intervals but not to exceed one-week intervals, and whenever a bulb is changed, reflectors and filters should be cleaned and checked for integrity. Cracked or broken UV filters should be replaced immediately. Defective bulbs must also be replaced before further use. See Table 2.

20.5 *Dry Particle Quality Control Checks*—In order to assure uniform and consistent performance from the dry magnetic powder selected for use, it is advisable that all incoming powders be certified or checked for conformance with quality control standards established between the user and supplier.

20.5.1 *Contamination:*

20.5.1.1 *Degradation Factors*—Dry magnetic particles are generally very rugged and perform with a high degree of consistency over a wide process envelope. Their performance, however, is susceptible to degradation from such contaminants as moisture, grease, oil, rust and mill scale particles, nonmagnetic particles such as foundry sand, and excessive heat. These contaminants will usually manifest themselves in the form of particle color change and particle agglomeration, the degree of which will determine further use of the powder. Over-heated dry particles can lose their color, thereby reducing the color contrast with the part and thus hinder part examination. Particle agglomeration can reduce particle mobility during processing, and large particle agglomerates may not be retained at an indication. Dry particles should not be recycled as fractionation, the subsequent depletion of finer particles from the aggregate powder composition, degrades the quality of the particles.

20.5.1.2 *Ensuring Particle Quality*—To ensure against deleterious effects from possible contaminants, it is recommended that a routine performance check be conducted (see 20.8.3).

20.6 *Wet Particle Quality Control Checks*—The following checks for wet magnetic particle suspensions should be conducted at startup and at regular intervals to assure consistent performance. See Table 2. Since bath contamination will occur as the bath is used, monitoring the working bath at regular intervals is essential.

20.6.1 *Determining Bath Concentration*—Bath concentration and sometimes bath contamination are determined by measuring its settling volume through the use of a pear-shaped centrifuge tube with a 1-mL stem (0.05-mL divisions) for fluorescent particle suspensions or a 1.5-mL stem (0.1-mL divisions) for nonfluorescent suspensions. (See Appendix X5.) Before sampling, the suspension should be run through the recirculating system for at least 30 min to ensure thorough mixing of all particles which could have settled on the sump screen and along the sides or bottom of the tank. Take a 100-mL portion of the suspension from the hose or nozzle into a clean, non-fluorescing centrifuge tube, demagnetize and allow it to settle for approximately 60 min with petroleum distillate suspensions or 30 min with water-based suspensions before reading. These times are average times based upon the most commonly used products; actual times should be adjusted so that the particles have substantially settled out of suspension. The volume settling out at the bottom of the tube is indicative of the particle concentration in the bath.

20.6.2 *Sample Interpretation*—If the bath concentration is low in particle content, add a sufficient amount of particle materials to obtain the desired concentration; if the suspension is high in particle content, add sufficient vehicle to obtain the desired concentration. If the settled particles appear to be loose agglomerates rather than a solid layer, take a second sample. If still agglomerated, the particles may have become magnetized; replace the suspension.

20.6.3 *Settling Volumes*—For fluorescent particles, the recommended settling volume (see 15.2) is from 0.1 to 0.4 mL in a 100-mL bath sample and from 1.2 to 2.4 mL per 100 mL of vehicle for non-fluorescent particles, unless otherwise approved by the Cognizant Engineering Organization (CEO). Refer to appropriate AMS document (3041, 3042, 3043, 3044, 3045, and/or 3046). For dual response particles, the recommended settling volume should be determined by the performance requirements and lighting environment of a given application as recommended by the manufacturer. See 8.5.5.

20.6.4 *Bath Contamination*—Both fluorescent and nonfluorescent suspensions should be checked periodically for contaminants such as dirt, scale, oil, lint, loose fluorescent pigment, water (in the case of oil suspensions), and particle agglomerates which can adversely affect the performance of the magnetic particle examination process. See Table 2.

20.6.4.1 *Carrier Contamination*—For fluorescent baths, the liquid directly above the precipitate should be evaluated with UV-A (black) light. Acceptable liquid will have a little fluorescence. Its color can be compared with a freshly made-up sample using the same materials or with an unused sample from the original bath that was retained for this purpose. If the "used" sample is noticeably more fluorescent than the comparison standard, the bath should be replaced.

20.6.4.2 *Particle Contamination*—The graduated portion of the tube should be evaluated under UV-A (black) light if the bath is fluorescent and under visible light (for both fluorescent and nonfluorescent particles) for striations or bands, differences in color or appearance. Bands or striations may indicate contamination. If the total volume of the contaminates, including bands or striations exceeds 30 % of the volume of magnetic particles, or if the liquid is noticeably fluorescent (see 20.6.4.1), the bath should be replaced.

20.6.5 *Particle Durability*—The durability of both the fluorescent and nonfluorescent magnetic particles in suspension should be checked periodically to ensure that the particles have not degraded due to chemical attack from the suspending oil or conditioned water vehicles or mechanically degraded by the rotational forces of the recirculating pump in a wet horizontal magnetic particle unit. Fluorescent magnetic particle breakdown in particular can result in a decrease in sensitivity and an increase in nonmagnetic fluorescent background. Lost fluorescent pigment can produce false indications that can interfere with the examination process.

20.6.6 *Fluorescent Brightness*—It is important that the brightness of fluorescent magnetic particle powder be maintained at the established level so that indication and background brightness can be kept at a relatively constant level. Variations in contrast can noticeably affect examination results. Lack of adequate contrast is generally caused by:

20.6.6.1 An increase in contamination level of the vehicle increasing background fluorescence, or

20.6.6.2 Loss of vehicle because of evaporation, increasing concentration, or

20.6.6.3 Degradation of fluorescent particles. See 20.6.8 for additional guidance.

20.6.7 *System Performance*—Failure to find a known discontinuity in a part or obtain the specified indications on the test ring (see 20.8.4) indicates a need for changing of the entire bath. If a part was used, it must have been completely demagnetized and cleaned so that no fluorescent background can be detected when viewed under UV-A (black) light with a surface intensity of at least 1000 μW/cm^2. If any background is noted that interferes with either detection or interpretation, the bath should be drained and a new suspension made.

20.6.8 *Determination of Particle Sensitivity*—Appendix X4 describes several devices that can demonstrate the sensitivity of either wet-method or dry-method particles. These devices contain permanent magnetization in some form and are independent of the magnetizing system. They should not be magnetized or demagnetized before or after use. Such devices can be useful whenever performance of the particles are subject to question or need to be verified.

20.7 *Bath Characteristics Control:*

20.7.1 *Oil Bath Fluids*—Properties of oil-bath fluids are described in AMS 2641 or A-A–59230.

20.7.2 *Water Bath Fluids*—Properties of conditioned water-bath fluids are described in AS 4792.

20.7.3 *Viscosity*—The recommended viscosity of the suspension is not to exceed 5 mm^2/s (5.0 cSt), at any temperature at which the bath may be used, when verified in accordance with Test Method D445.

20.7.4 *Flash Point*—The recommended flash point of wet magnetic particle light petroleum distillate suspension is a minimum of 200°F (93°C); use Test Method D93.

20.7.5 *Water Break Check for Conditioned Water Vehicles*—Properly conditioned water will provide proper wetting, particle dispersion, and corrosion protection. The water break check should be performed by flooding a part, similar in surface finish to those under examination, with suspension, and then noting the appearance of the surface of the part after the flooding is stopped. If the film of suspension is continuous and even all over the part, sufficient wetting agent is present. If the film of suspension breaks, exposing bare surfaces of the part, and the suspension forms many separate droplets on the surface, more wetting agent is needed or the part has not been sufficiently cleaned. When using the fluorescent method, this check should be performed independently under both UV-A (black) light and visible light.

20.7.6 *pH of Conditioned Water Vehicles*—The recommended pH of the conditioned water bath is between 7.0 and 10.5 as determined by a suitable pH meter or special pH paper.

20.8 *Verifying System Performance*—System performance checks must be conducted in accordance with a written procedure so that the verification is performed in the same manner each time.

20.8.1 *Production Verification Parts with Discontinuities*—A practical way to evaluate the performance and sensitivity of the dry or wet magnetic particles or overall system performance, or both, is to use representative verification parts with known discontinuities of the type and severity normally encountered during actual production examination. However, the usefulness of such parts is limited because the orientation and magnitude of the discontinuities cannot be controlled. The use of flawed parts with gross discontinuities is not recommended. (**Warning—**If such parts are used, they must be thoroughly demagnetized and cleaned after each use.)

20.8.2 *Fabricated Test Parts with Discontinuities*—Often, production verification parts with known discontinuities of the type and severity needed for evaluation are not available. As an alternative, fabricated verification specimens with discontinuities of varying degree and severity can be used to provide an indication of the effectiveness of the dry or wet magnetic particle examination process. If such parts are used, they should be thoroughly demagnetized and cleaned after each use.

20.8.3 *Test Plate*—A magnetic particle system performance verification plate, such as shown in Fig. 13 is useful for checking the overall performance of wet or dry techniques using prods and yokes. Recommended minimum dimensions are ten inches per side and nominal thickness of one inch. Discontinuities can be formed by controlled heating/cooling, EDM notches, artificial discontinuities in accordance with 14.2.2 or other means. (**Warning—**Notches should be filled flush to the surface with a nonconducting material, such as epoxy, to prevent the mechanical holding of the indicating medium.)

20.8.4 *Test Ring Specimen*—A verification (Ketos) ring specimen may also be used in evaluating and comparing the overall performance and sensitivity of both dry and wet, fluorescent and non-fluorescent magnetic particle techniques using a central conductor magnetization technique. Refer to Appendix X7 for further information.

20.8.4.1 *Using the Test Ring*—See Appendix X7 for further information.

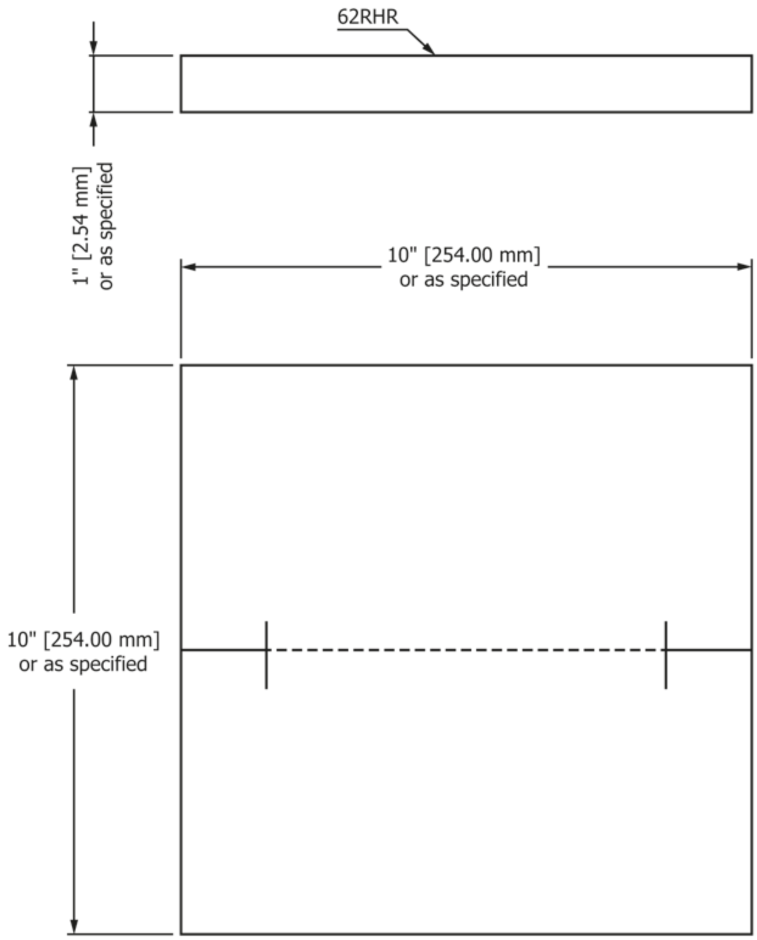


FIG. 13 Sample of a Magnetic Particle Performance Verification Plate. Defects are formed and located in accordance with plate manufacturers' specifications.

20.8.5 *Magnetic Field Indicators:*

20.8.5.1 *"Pie" Field Indicator*—The magnetic field indicator shown in Fig. 14 relies on the slots between the pie shaped segments to show the presence and the approximate direction of the external magnetic field. Because "pie" field indicators are constructed of highly permeable material with 100 % through wall flaws, indications does not mean that a suitable field strength is present for the location of relevant indications in the part under examination. The "pie" field indicator is used with the magnetic particles applied across the copper face of the indicator (the slots are against the piece) simultaneously with the magnetizing force. Typical "pie" field indicators show a clear indication in a five gauss external field. These devices are generally used as instructional aids.

20.8.5.2 *Slotted Shims*—Several types of slotted shims exist. Refer to AS 5371 and to illustrations in Appendix X2.

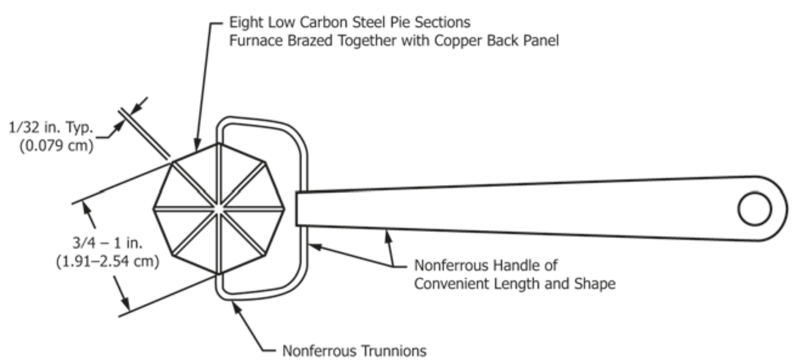


FIG. 14 Pie Field Indicator

21. Procedures

21.1 When specified a procedure should be written for all magnetic particle examinations and should include as a minimum the following information. A sketch is usually used for illustrating part geometry, techniques, and areas for examination. This sketch may also be used for recording location of magnetic field indicators and for recording location of discontinuities.

21.1.1 Area to be examined (entire part or specific area),

21.1.2 Type of magnetic particle material (dry or wet, visible or fluorescent),

21.1.3 Magnetic particle equipment,

21.1.4 Part surface preparation requirements,

21.1.5 Magnetizing process (continuous, true-continuous, residual),

21.1.6 Magnetizing current (alternating, half-wave rectified AC, full-wave rectified AC, direct),

21.1.7 Means of establishing part magnetization (direct-prods, head/tailstock contact or cable wrap, indirect-coil/cable wrap, yoke, central conductor, and so forth),

21.1.8 Direction of magnetic field (circular or longitudinal),

21.1.9 System performance/sensitivity checks,

21.1.10 Magnetic field strength (ampere turns, field density, magnetizing force, and number and duration of application of magnetizing current),

21.1.11 Application of examination media,

21.1.12 Interpretation and evaluation of indications,

21.1.13 Type of records including accept/reject criteria,

21.1.14 Demagnetizing techniques, if required, and

21.1.15 Post-examination cleaning, if required.

21.2 *Written Reports*—Written reports should be prepared as agreed upon between the testing agency/department and the purchaser/user.

22. Acceptance Standards

22.1 The acceptability of parts examined by this method is not specified herein. Acceptance standards are a matter of agreement between the manufacturer and the purchaser and should be stated in a referenced contract, specification, or code.

23. Safety

23.1 Those involved with hands-on magnetic particle examination exposure to hazards include:

23.1.1 *Electric Shock and Burns*—Electric short circuits can cause shock and particularly burns from the high amperages at relatively low voltages that are used. Equipment handling water suspensions should have good electrical grounds.

23.1.2 *Flying Particles*—Magnetic particles, particularly the dry ones, dirt, foundry sand, rust, and mill scale can enter the eyes and ears when they are blown off the part when applying them to a vertical or overhead surface or when cleaning an examined surface with compressed air. Dry particles are easy to inhale and the use of a dust respirator is recommended.

23.1.3 *Falls*—A fall from a scaffold or ladder if working on a large structure in the field or shop.

23.1.4 *Fire*—Ignition of a petroleum distillate bath.

23.1.5 *Environment*—Doing magnetic particle examination where flammable vapors are present as in a petrochemical plant or oil refinery. Underwater work has its own set of hazards and should be addressed independently.

23.1.6 *Wet Floors*—Slipping on a floor wetted with a particle suspension.

23.1.7 *Shifting or Dropping of Large Components*—Large components, especially those on temporary supports can shift during examination or fall while being lifted. In addition, operators should be alert to the possibility of injury to body members being caught beneath a sling/chain or between head/tail stock and the piece.

23.1.8 *Ultraviolet Light Exposure*—Ultraviolet light can adversely affect the eyes and skin. Safety goggles designed to absorb UV-A (black light) wavelength radiation are suggested where high intensity blacklight is used.

23.1.9 *Materials and Concentrates*—The safe handling of magnetic particles and concentrates are governed by the supplier's Material Safety Data Sheets (MSDS). The MSDS conforming to 29 CFR 1910.1200 or equivalent must be provided by the supplier to any user and must be prepared in accordance with FED-STD-313.

23.1.10 *Equipment Hazards*—Because of the large breadth of equipment available, unique safety hazards may exist and should be addressed on a case by case basis.

24. Precision and Bias

24.1 The methodology described in the practice will produce repeatable results provided the field has the proper orientation with respect to the discontinuities being sought.

24.2 It must be recognized that the surface condition of the material being examined, the material's magnetic properties, its shape, and control of the factors listed in 20.1 influence the results obtained.

25. Keywords

25.1 dye; evaluation; examination; fluorescent; inspection; magnetic particle; nondestructive; testing

ANNEX

(Mandatory Information)

A1. TYPICAL MAGNETIC PARTICLE INDICATIONS

A1.1 Surface discontinuities with few exceptions produce sharp and distinct magnetic particle indications. Near-surface discontinuities on the other hand produce less distinct or fuzzy magnetic particle indications in comparison to surface discontinuities; the magnetic particle indications are broad rather than sharp and the particles are less tightly held.

A1.2 *Wet Method:*

A1.2.1 *Fluorescent*—Indications of surface cracks, surface indications, and an indication of a near surface discontinuity are shown in Figs. A1.1-A1.6.

A1.2.2 *Nonfluorescent*—Indications of surface cracks are shown in Figs. A1.7-A1.16.

A1.3 *Dry Method*—Indications of surface cracks are shown in Figs. A1.17-A1.23.

A1.4 Nonrelevant indications are shown in Figs. A1.24-A1.26.

FIG. A1.1 Axle with Circumferential Crack in Shoulder

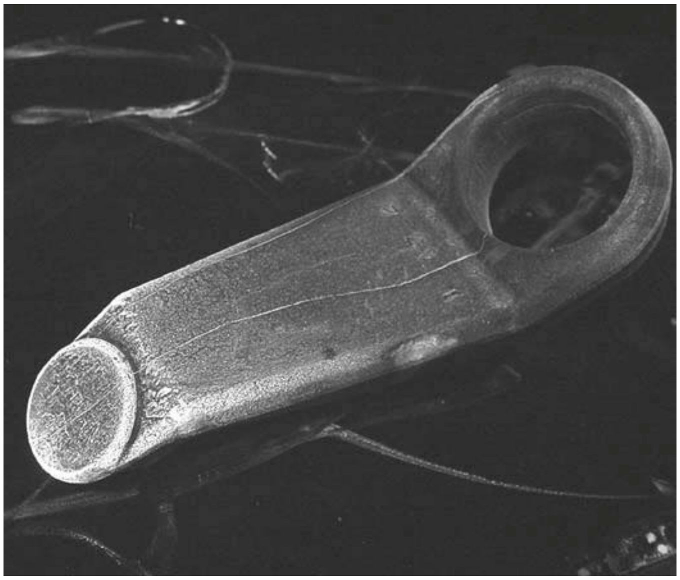


FIG. A1.2 Arm with Two Longitudinal Indications

FIG. A1.3 Hub with Both Radial and Longitudinal Indications

FIG. A1.4 Crankshaft with Various Longitudinal Indications

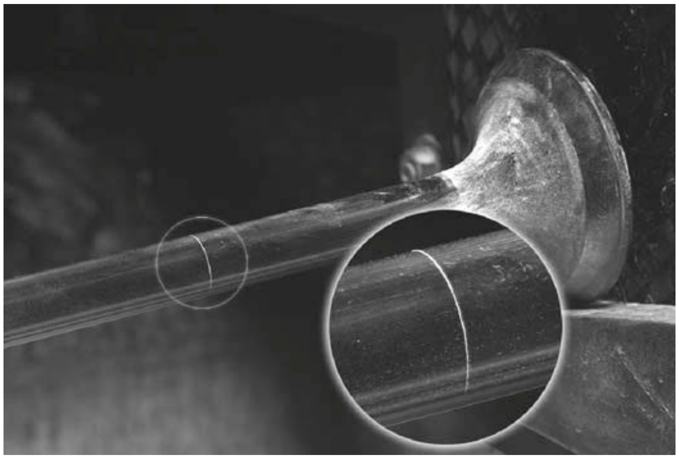


FIG. A1.5 Valve with Indication on the Stem

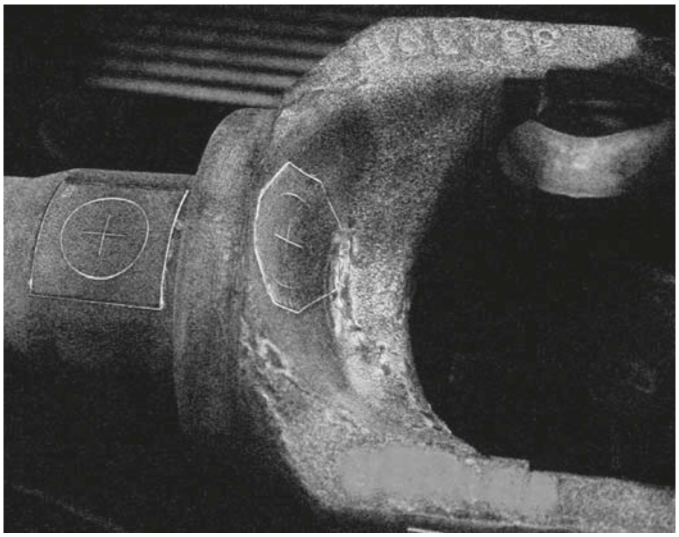


FIG. A1.6 Yoke Showing Balanced QQIs

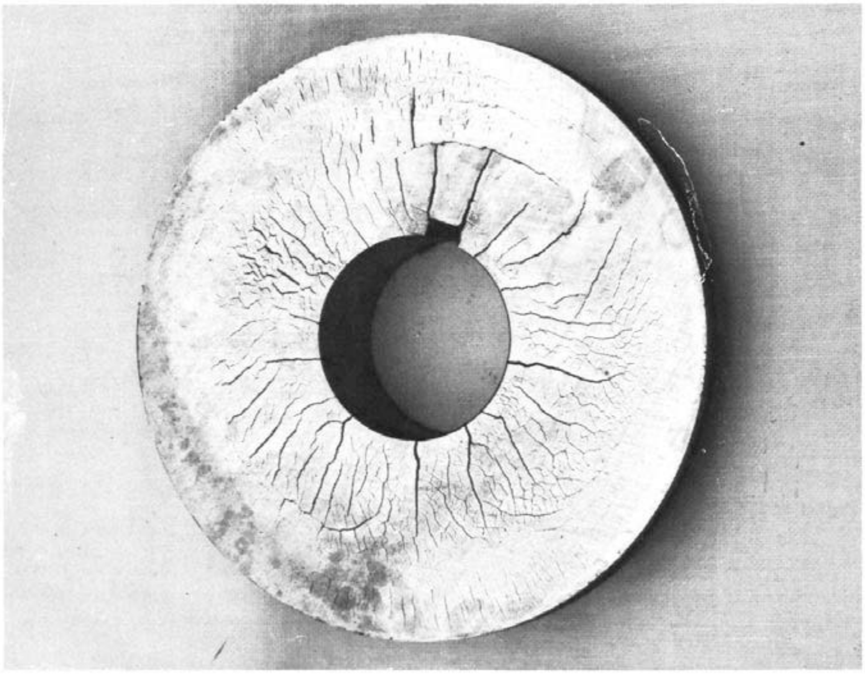


FIG. A1.7 Indications of Surface Cracking (Produced by Central Conductor Magnetization DC Continuous)

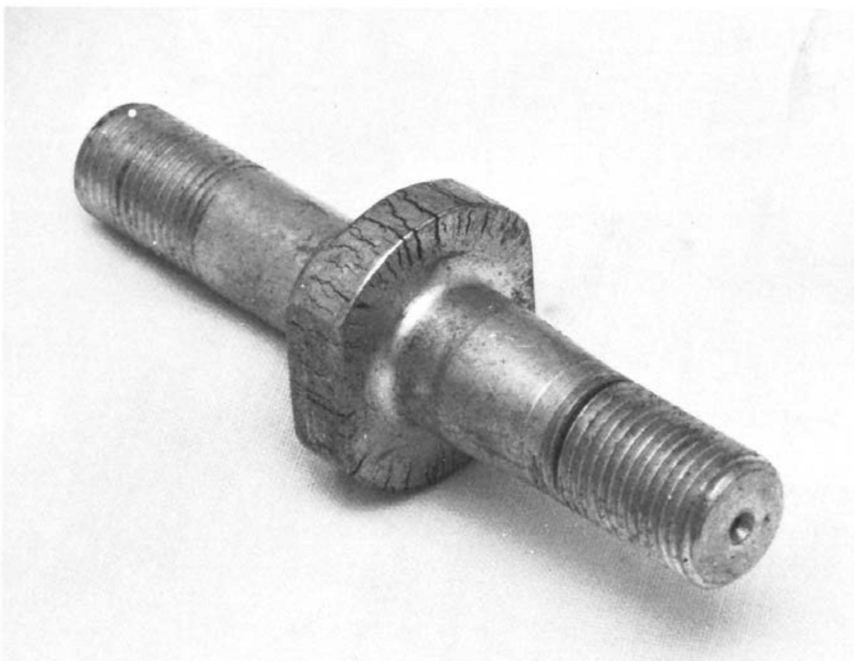


FIG. A1.8 Indications of Surface Cracking (Produced by Circular Direct Magnetization DC Continuous)

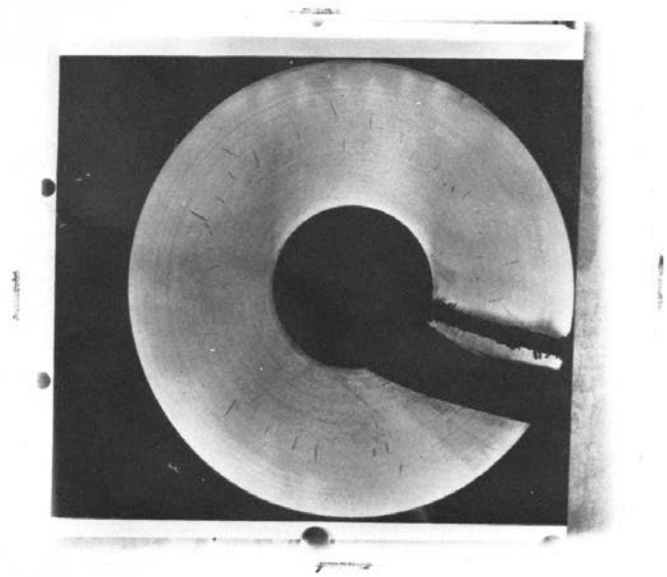


FIG. A1.9 Indications of Surface Cracks (Produced by Central Conductor Magnetization DC Continuous)

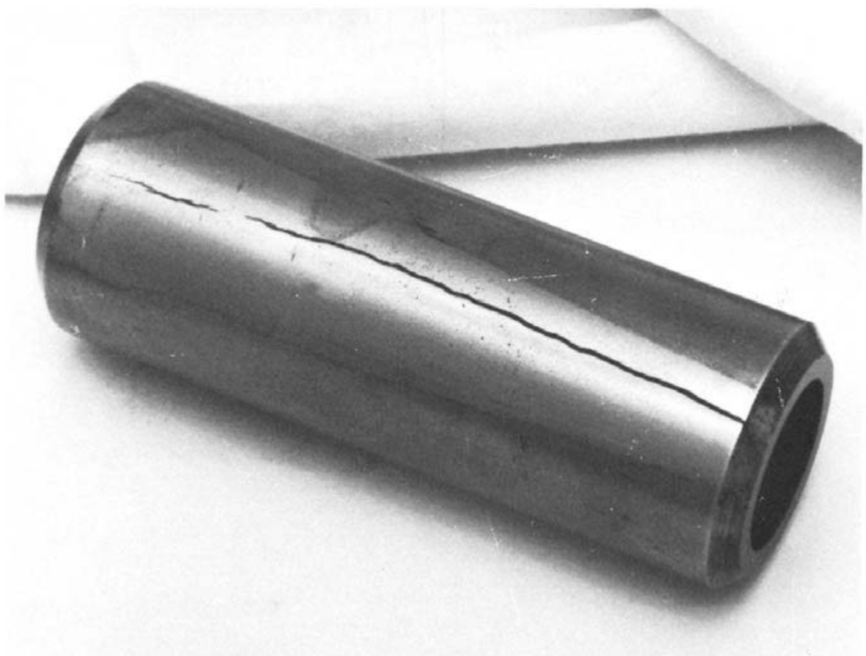


FIG. A1.10 Indications of Surface Cracks (Produced by Circular Indirect Magnetization DC)

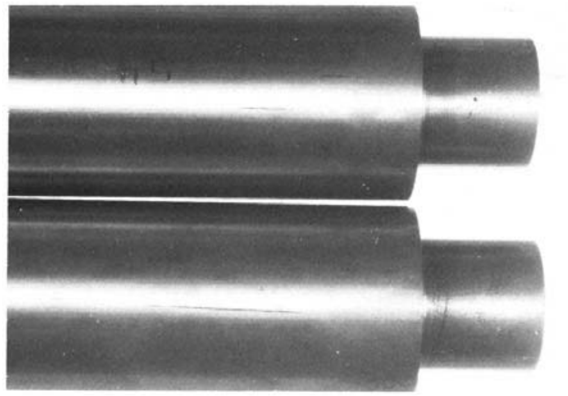


FIG. A1.11 Indications of a Near-Surface Discontinuity (Produced by Circular Direct Magnetization AC Continuous)

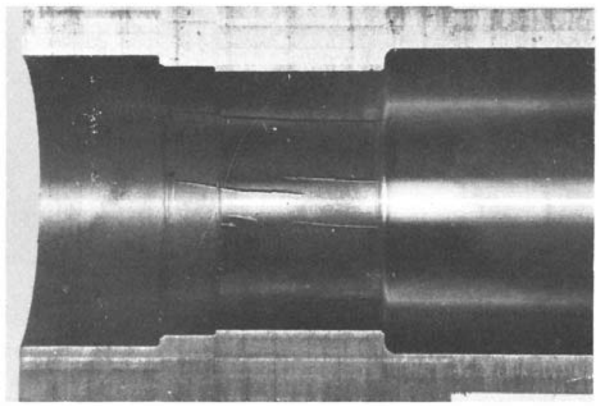


FIG. A1.12 Indications of Near-Surface Indications (Produced by Circular Direct Magnetization AC Continuous)

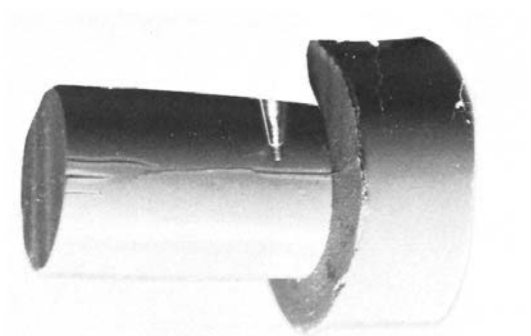


FIG. A1.13 Magnetic Rubber Indications of Surface Cracks in Aircraft Fastener Holes (Produced by Yoke Magnetization DC Continuous)

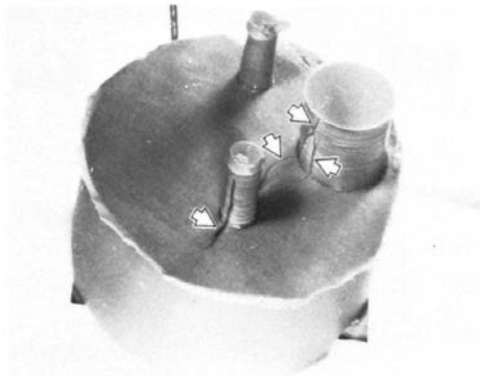


FIG. A1.14 Magnetic Rubber Indications of Surface Cracks in Aircraft Fastener Holes (Produced by Yoke Magnetization DC Continuous)

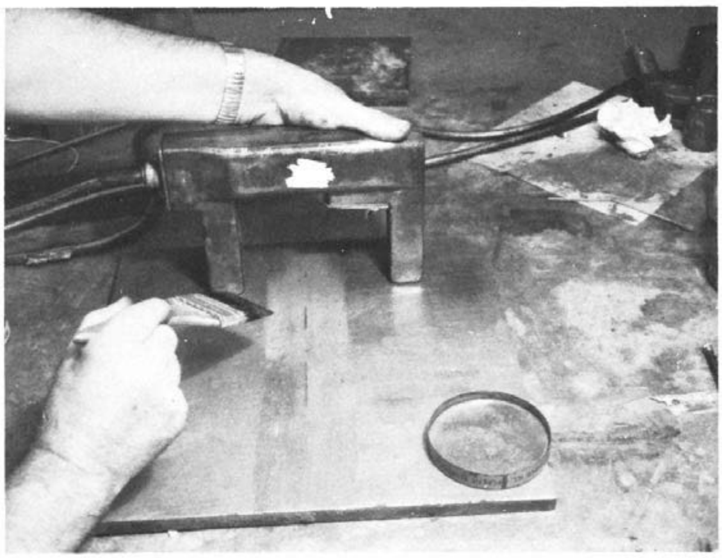


FIG. A1.15 Magnetic Slurry Indications of Surface Cracks in Weldment (Produced by Yoke Magnetization, AC Continuous)

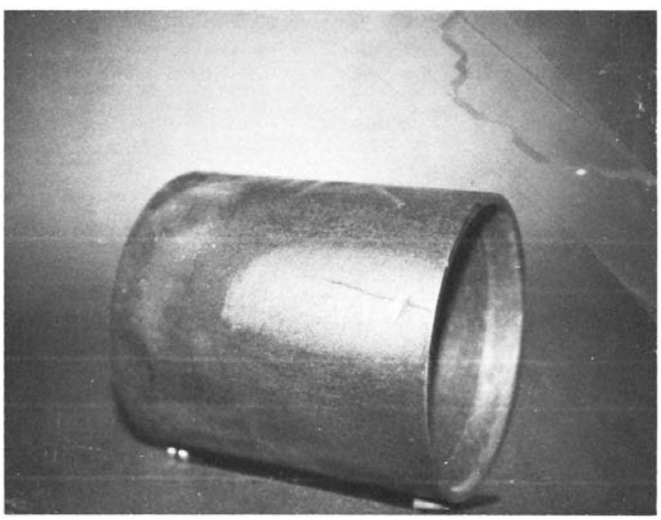


FIG. A1.16 Magnetic Slurry Indications of Surface Cracks (Produced by Yoke Magnetization, AC Continuous)

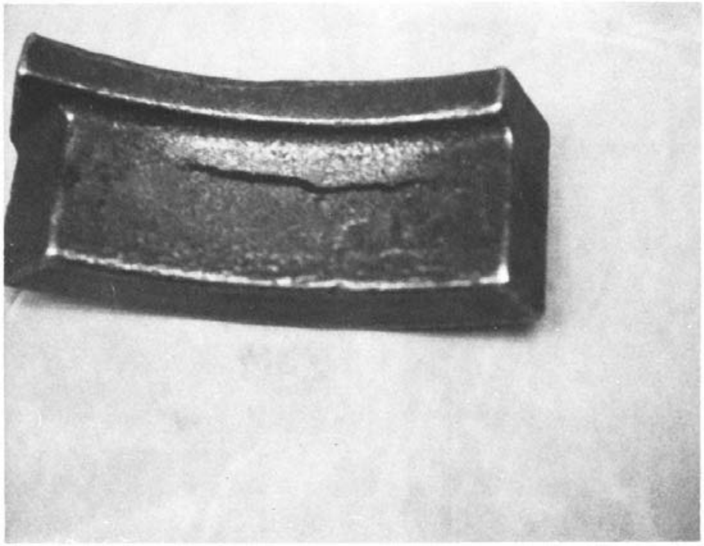


FIG. A1.17 Indications of a Near-Surface Discontinuity (Produced by Prod Magnetization, HWDC Continuous)

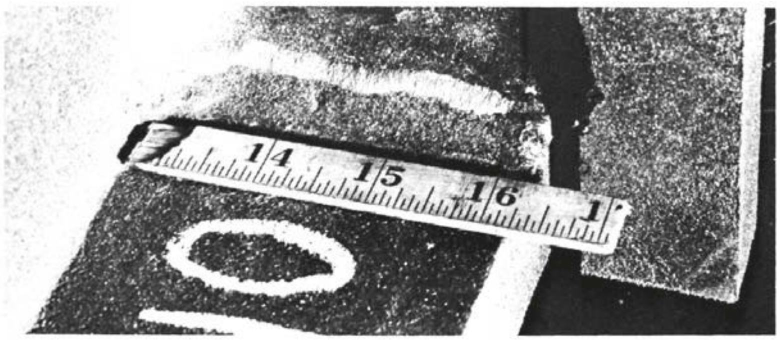


FIG. A1.18 Indications of a Near-Surface Discontinuity (Produced by Prod Magnetization, HWDC Continuous)

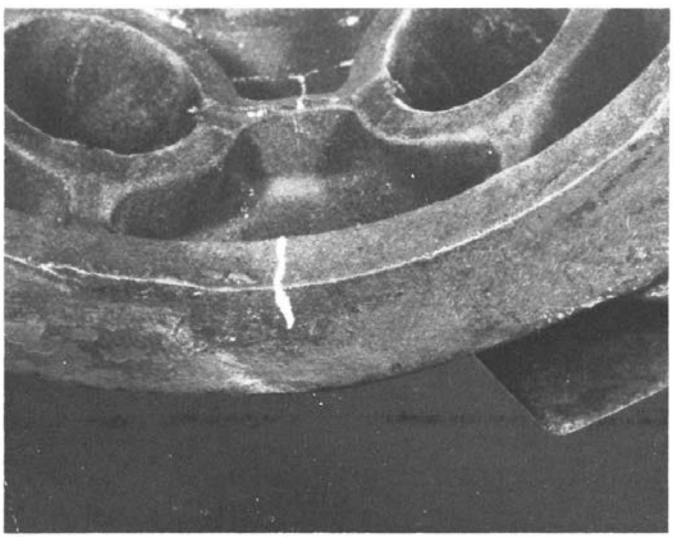


FIG. A1.19 Indication of Surface Cracks (Produced by Circular Indirect Magnetization, AC Continuous)

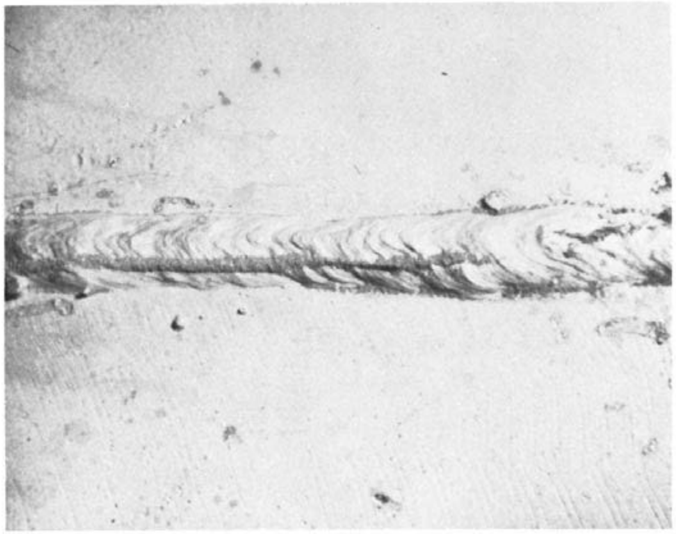


FIG. A1.20 Indication of Surface Cracks (Produced by Prod Magnetization, AC Continuous)

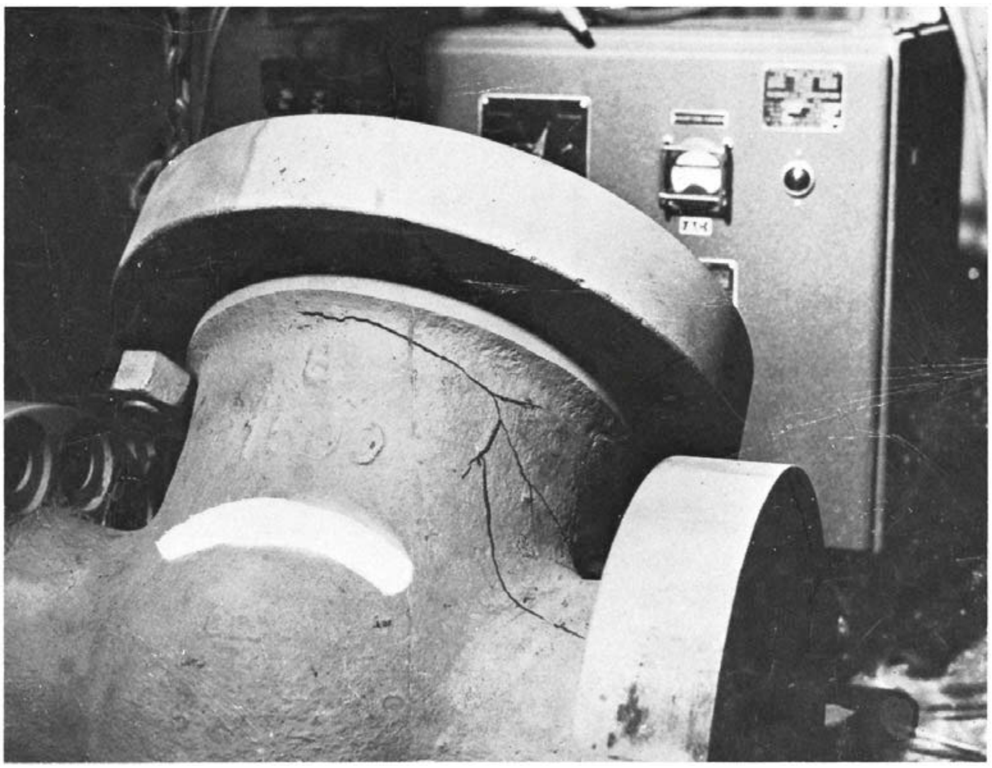


FIG. A1.21 Indications of Surface Cracks (Produced by Prod Magnetization, DC Continuous)

FIG. A1.22 Indications of Surface Cracks (Produced by Circular Direct Magnetization, AC Continuous)

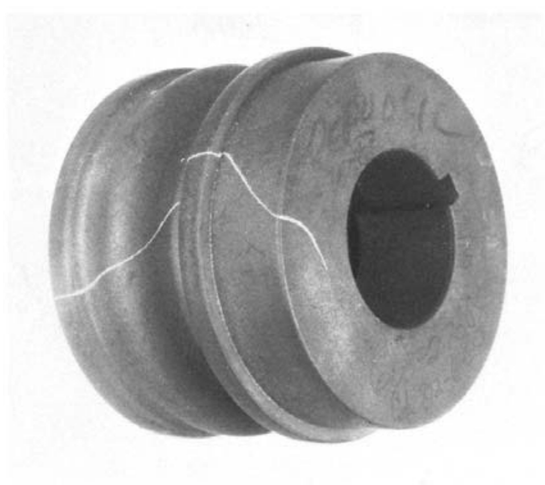


FIG. A1.23 Indications of Surface Cracks (Produced by Central Conductor Magnetization, AC Continuous)

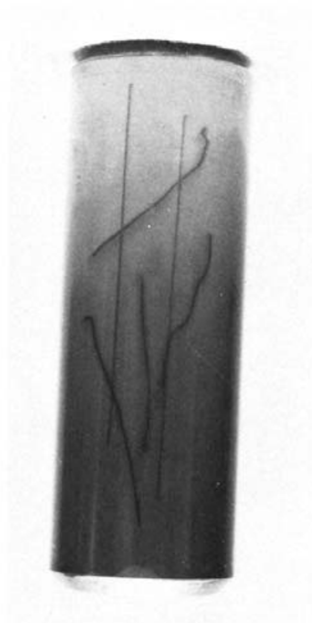


FIG. A1.24 Nonrelevant Indications of Magnetic Writing (Produced by Direct Magnetization, DC Continuous)

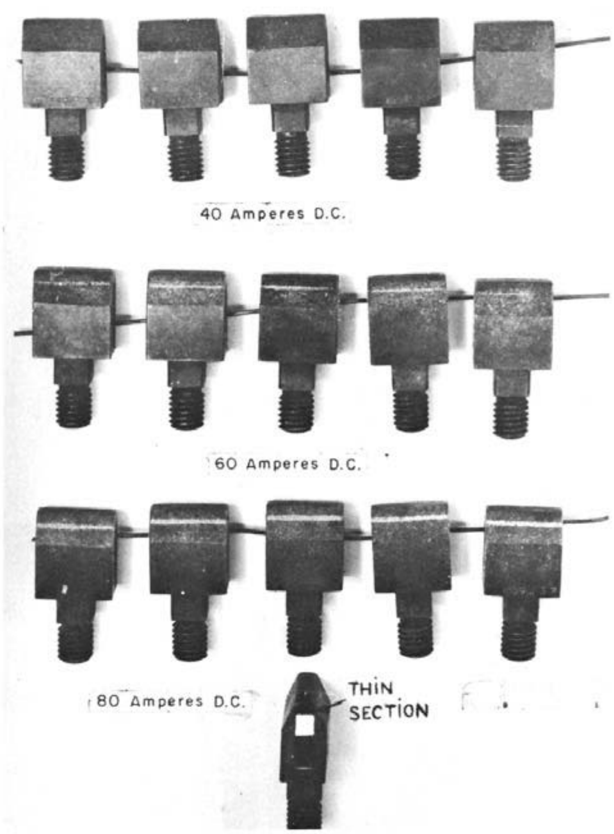


FIG. A1.25 Nonrelevant Indications Due to Change in Section on a Small Part (Produced by Indirect, Circular Magnetization, DC Continuous)

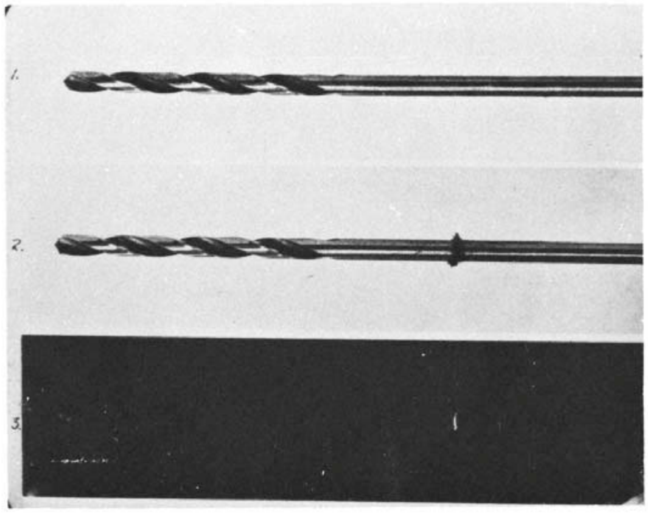


FIG. A1.26 Nonrelevant Indications of Junction Between Dissimilar Materials (Produced by Coil DC Residual Magnetization)

APPENDIXES

(Nonmandatory Information)

X1. FLEXIBLE LAMINATED STRIPS FOR MAGNETIC PARTICLE TESTING

X1.1 Flexible laminated strips are typically used to ensure proper field direction during magnetic particle testing. The longitudinal axis of the strip should be placed perpendicular to the direction of the magnetic field of interest in order to generate the strongest particle indications on the strip.

X1.1.1 The strips are available in two types, *General Use* and *Aerospace Use*. Both types of strip contain a steel layer sandwiched between two brass plates that are 0.0020 in. (0.0508 mm) thick. The bottom brass layer acts as a lift-off of 0.0020 in. (0.0508 mm) from the examination surface. The brass is non-magnetic and functions only to provide lift-off and to protect the steel layer. The entire strip may have a polymeric coating for further protection.

X1.1.2 The longitudinal dimension of the strips is 1.95 in. (50 mm) and the width of the strip is 0.47 in. (12 mm).

X1.1.3 Both types of strips contain three longitudinal slots in the center steel layer.

X1.1.3.1 The widths of the slots in the *General Use* strip are 0.0075 in. (0.1905 mm), 0.009 in. (0.2286 mm), and 0.010 in. (0.254 mm).

X1.1.3.2 The widths of the slots in the *Aerospace Use* strip are 0.003 in. (0.0762 mm), 0.004 in. (0.1016 mm), and 0.005 in. (0.127 mm).

X1.1.4 The center steel layer of the strips is made of a high "μ" magnetic material.

X1.1.5 Strips shall be placed in the area(s) of interest of the part or surface being examined. Use enough strips, or place the strips in multiple areas, to ensure that proper field directions are obtained.

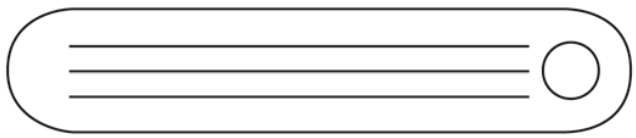


FIG. X1.1 The longitudinal lines represent the location of the slots cut into the center steel layer of either the General or Aerospace flexible laminated strips.

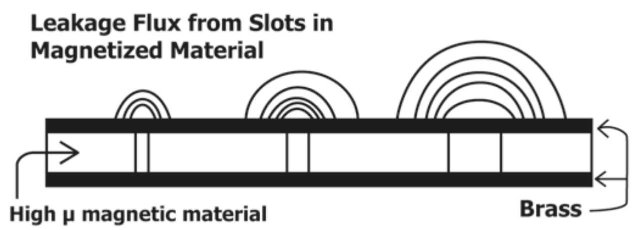


FIG. X1.2 A cross-sectional view illustrates the magnetic leakage flux generated by the slots in the central steel layer of a flexible laminated strip exposed to a magnetic field perpendicular to the strip axis.

X1.2 Instructions for the Use of Flexible Laminated Strips

X1.2.1 *Application of Strips*—Flexible laminated strips, as shown in Fig. X1.3 and Fig. X1.4, require specific handling, attachment, and care for accurate indication of magnetic field direction.

X1.2.2 Strips are manufactured from high permeability carbon steel and must be protected from corrosion when not in

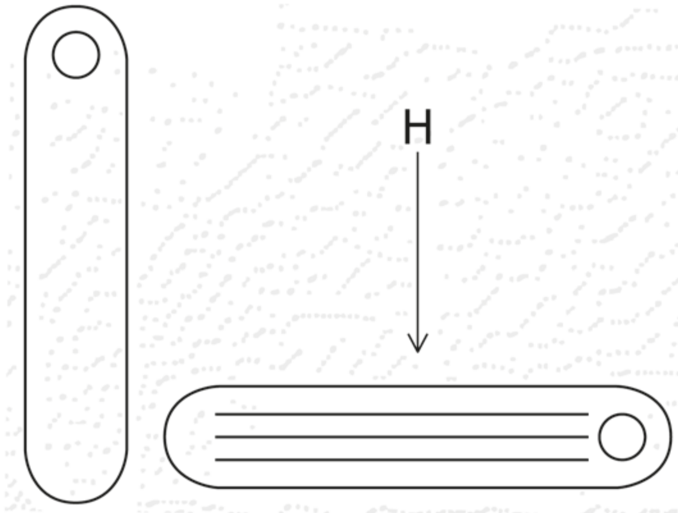


FIG. X1.3 Particle indications are strongest when applied magnetic field (H) is of sufficient strength and perpendicular to the longitudinal axis of the strip. No indications will form when the longitudinal axis is parallel to the applied field or the strength of H is insufficient.

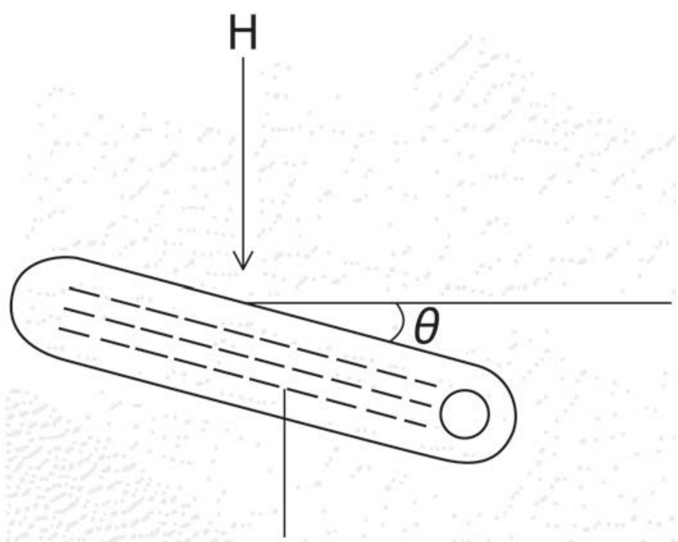


FIG. X1.4 Weak particle indications can mean that the longitudinal axis of the strip is at an angle (θ) from the applied magnetic field (H), or that the applied field is not strong enough to generate indications.

use. They should be stored in a dry location. Before placing the strip onto the part, both the strip and part shall be clean and dry.

X1.2.3 The strip shall be placed in intimate contact with material to be examined. The strip may be held in place manually or with the use of an adhesive or tape.

X1.2.3.1 If the strip is to be fastened to the part by using an adhesive or tape, select one (such as Scotch brand 191, 471, or 600 series) that prevents the magnetic particle suspension from entering between the strip and part.

X1.2.3.2 Tape may be used to secure the strip and shall have the following properties:

X1.2.3.2.1 Good adhesion to steel,

X1.2.3.2.2 Impervious to the suspension used, and

X1.2.3.2.3 Tape shall be non-fluorescent (for fluorescent suspensions).

X1.2.3.3 If the tape becomes loose, allowing the suspension to seep under the strip, the tape and strip shall be carefully removed, the strip and the part shall be cleaned, and the strip shall be reattached.

X1.2.3.4 Any tape or adhesive used to secure the strip to the part shall neither cover nor interfere with the visibility of the indications.

X1.2.4 Re-use of the strips is acceptable, provided they are not distorted when removed and intimate contact is achieved when replaced.

X1.2.5 Use care when applying the suspension to the strips. Proper strip indications may not form unless the suspension is applied in a gentle manner.

X1.2.6 The active center layer of the strips are made of a low retentively and high permeability material. Use of the strips in verifying the presence of residual magnetic fields can only be made with approval of the Cognizant Engineering Organization.

X1.2.7 *Determining Field Direction*—Strips provide the strongest particle indications on the three lines when positioned such that the longitudinal axis of the strip is perpendicular to the applied magnetic field. A strip whose longitudinal axis is parallel to the applied field will not provide any particle indications. Refer to Fig. X1.3 and Fig. X1.4.

X1.2.7.1 To use strips to determine the field direction, first determine the location(s) for the strip(s) to be placed.

X1.2.7.2 Position a strip onto the surface so that it is perpendicular to the direction of the applied magnetic field.

X1.2.7.2.1 A second strip may be placed perpendicular to the first.

X1.2.7.3 Using the continuous method, begin by starting the amperage selection at a minimum level and increasing the amperage slowly until the indications of the lines in one or both strip(s) are readily observed.

X1.2.7.4 If both strips show particle indications, the applied field is at an angle of between 30° to 60° to them. If no indications are visible in either strip when the field is applied, the field is not strong enough to generate indications.

X1.2.7.5 Actual field strength measurements (in the air at the point of measurement) can be obtained by placing a Hall Effect probe adjacent to the strip or at a nearby location where probe placement can easily be replicated.

X2. REFERENCE STANDARD NOTCHED SHIMS FOR MAGNETIC PARTICLE TESTING IN ACCORDANCE WITH AS 5371

X2.1 The following standard flawed shims are typically used to establish proper field direction and ensure adequate field strength during technique development in magnetic particle examination. The shims of Fig. X2.1 may be used to ensure the establishment of fields in the unidirectional magnetization method and to ensure the establishment and balance of fields in the multidirectional magnetization method.

X2.1.1 Except for shims illustrated in Fig X2.3, the shims are available in two thicknesses, 0.002 in. (0.05 mm) and 0.004 in. (0.10 mm). Thinner shims are used when the thicker shims cannot conform to the part surface in the area of interest.

X2.1.2 The shims are available in two sizes, 0.75 in. (19 mm) square for Figs. X2.1 and X2.2 and 0.79 in. (20 mm) square of Fig. X2.3. The shims of Fig. X2.3 are cut, by the user, into four 0.395 in. (10 mm) square shims for use in restricted areas.

X2.1.3 Shims should be low carbon steel, AMS 5062 or equivalent.

X2.1.4 Shims should be used as specified in AS 5371. Shims are placed in the area(s) of interest with notches toward the surface of the part being examined. Use enough shims or place the shims in multiple areas to ensure proper field directions and strengths are obtained.

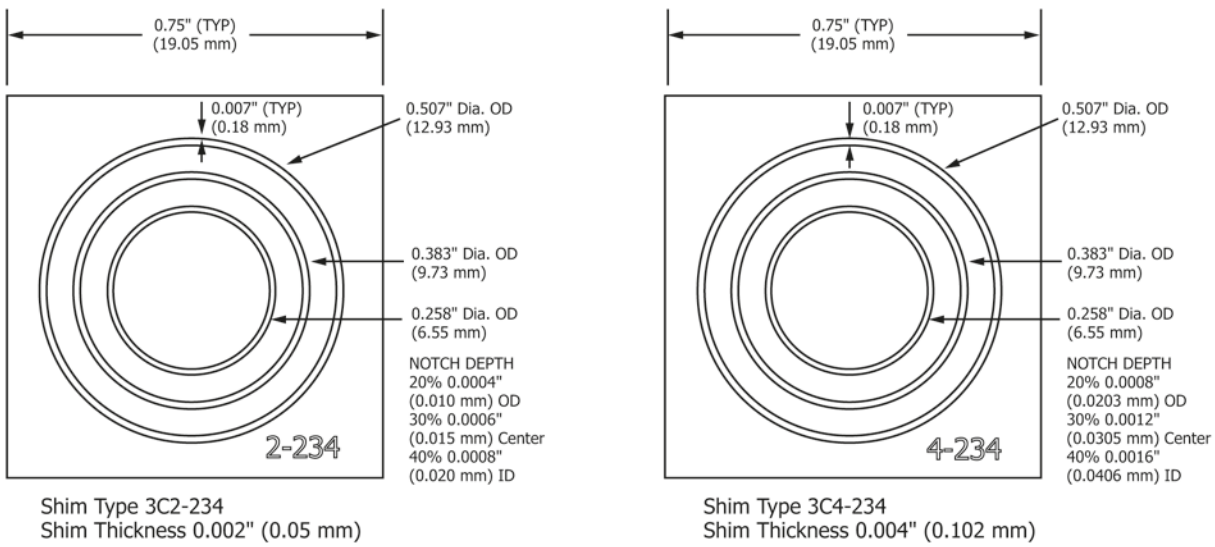
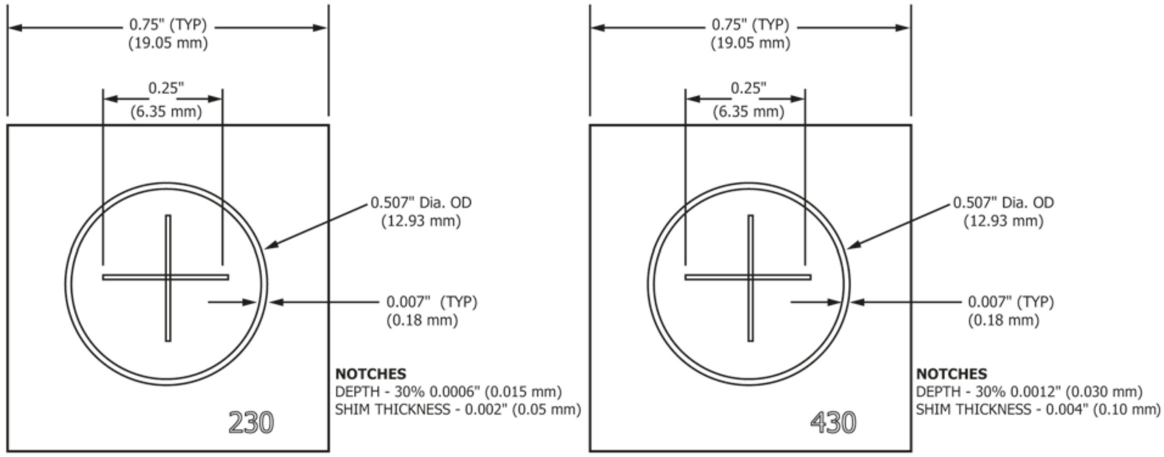


FIG. X2.1 Shim Thicknesses for Shim Types 3C2-234 and 3C4-234



Shim Type CX-230 **Shim Type CX-430**

FIG. X2.2 Shim Types CX-230 and CX-430

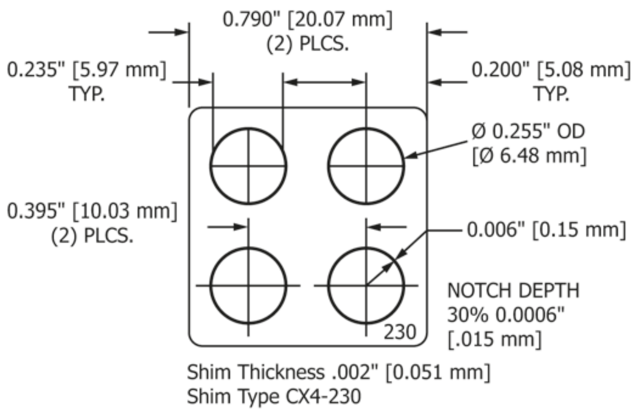


FIG. X2.3 Shim Thickness for Shim Type CX4-230

X3. EMPIRICAL FORMULAS

X3.1 This appendix has empirical formulas for establishing magnetic field strengths; they are rules of thumb. As such, they must be used with judgment. Their use may lead to:

X3.1.1 Over magnetization, which causes excessive particle background that makes interpretation more difficult if not impossible.

X3.1.2 Poor coverage.

X3.1.3 Poor choice of examination geometries.

X3.1.4 A combination of the above.

X3.2 *Guidelines for Establishing Magnetic Fields*—The following guidelines can be effectively applied for establishing proper levels of circular and longitudinal magnetization using empirical formulas.

X3.2.1 *Circular Magnetization*
Magnetic Field Strength:

X3.2.1.1 *Direct Circular Magnetization*
When magnetizing by passing current directly through the part the nominal current should generally be 300–800 A/in. of part diameter (12 to 32 A/mm). The diameter of the part should be taken as the greatest distance between any two points on the outside circumference of the part. Currents will normally be 500 A/in. (20 A/mm) or lower, with the higher currents up to 800 A/in. (32 A/mm) being used to examine for inclusions or to examine low-permeability alloys. Amperages of less than 300 A/in. may be used when part configuration dictates and approval is obtained from the Level III and the Cognizant Engineering Organization. The field strengths generated through the use of empirical formulas should be verified with a Hall effect gaussmeter or AS 5371 shims.

X3.2.1.2 *Central Conductor Induced Magnetization*
When using offset central conductors the conductor passing through the inside of the part is placed against an inside wall of the part. The current should be from 12 A per mm of part diameter to 32 A per mm of part diameter (300 to 800 A/in.). The diameter of the part should be taken as the largest distance between any two points on the outside circumference of the part. Generally, currents will be 500 A/in. (20 A per mm) or

lower with the higher currents (up to 800 A/in.) being used to examine for inclusions or to examine low permeability alloys such as precipitation-hardening steels. For examinations used to locate inclusions in precipitation-hardening steels even higher currents, up to 1000 A/in. (40 A per mm) may be used. The distance along the part circumference, which may be effectively examined should be taken as approximately four times the diameter of the central conductor, as illustrated in Fig. 10(b). The entire circumference should be examined by rotating the part on the conductor, allowing for approximately a 10 % magnetic field overlap. Less overlap, different current levels, and larger effective regions (up to 360°) may be used if the presence of suitable field levels is verified.

X3.2.2 *Air-Core Coil Longitudinal Magnetization* Longitudinal part magnetization is produced by passing a current through a multi-turn coil encircling the part, or section of the part to be examined. A magnetic field is produced parallel to the axis of the coil. The unit of measurement is ampere turns (NI) (the actual amperage multiplied by the number of turns in the encircling coil or cable). The effective is variable and is a function of the fill factor and field extends on either side of the coil. The effective distance can easily be determined by use of a Gauss (Tesla) meter to identify where the flux lines are leaving to complete their return loop. Long parts should be examined in sections that do not exceed this length. There are four empirical longitudinal magnetization formulas employed for using encircling coils, the formula to be used depending on the fill factor. The formulas are included for historical continuity only. If used its use should be limited to simple shaped parts. It would be quicker and more accurate to use a Gauss (Tesla) meter, lay its probe on the part and measure the field rather than to calculate using the formulas.

X3.2.2.1 *Low Fill-Factor Coils* In this case, the cross-sectional area of the fixed encircling coil greatly exceeds the cross-sectional area of the part (less than 10 % coil inside diameter). For proper part magnetization, such parts should be placed well within the coils and close to the inside wall of the coil. With this low fill-factor, adequate field strength for eccentrically positioned parts with a length-over-diameter ratio (*L/D*) between 3 and 15 is calculated from the following equations:

(1) Parts with Low Fill-Factor Positioned Close to Inside Wall of Coil:

$$NI = K/(L/D)\ (\pm 10\,\%) \qquad \text{(X3.1)}$$

where:

N = number of turns in the coil,
I = coil current to be used, amperes (A),
K = 45 000 (empirically derived constant),
L = part, length, in., (see Note),
D = part diameter, in.; for hollow parts, see X3.2.2.4, and
NI = ampere turns.

For example, a part 15 in. (38.1 cm) long with 5-in. (12.7-cm) outside diameter has an *L/D* ratio of 15/5 or 3. Accordingly, the ampere turn requirement (NI = 45 000/3) to provide adequate field strength in the part would be 15 000 ampere turns. If a five-turn coil or cable is used, the coil amperage requirements would be (I = 15 000/5) = 3000 A (±10 %). A500 turn coil would require 30 A (±10 %).

(2) Parts with a Low Fill-Factor Positioned in the Center of the Coil:

$$NI = KR/\{(6L/D) - 5\}(\pm 10\,\%) \qquad \text{(X3.2)}$$

where:

N = number of turns in the coil,
I = coil current to be used, A,
K = 43 000 (empirically derived constant),
R = coil radius, in.,
L = part length, in. (see Note),
D = part diameter, in., for hollow parts (see X3.2.2.4), and
NI = ampere turns.

For example, a part 15 in. (38.1 cm) long with 5-in. (12.7-cm) outside diameter has a *L/D* ratio of 15/5 or 3. If a five-turn 12-in. diameter (6-in. radius) (30.8-cm diameter (15.4-cm radius)) coil or cable is used, (*1*) the ampere turns requirement would be as follows:

$$NI = \frac{(43\,000 \times 6)}{((6 \times 3) - 5)} \text{ or } 19\,846$$

and (*2*) the coil amperage requirement would be as follows:

$$\frac{19\,846}{5}\ or\ 3\,969\ A\ (\pm 10\,\%)$$

X3.2.2.2 *Intermediate Fill-Factor Coils* When the cross section of the coil is greater than twice and less than ten times the cross section of the part being examined:

$$NI = (NI)_{\text{hf}}(10 - Y) + (NI)_{\text{lf}}(Y - 2)/8 \qquad \text{(X3.3)}$$

where:

NI_{hf} = value of NI calculated for high fill-factor coils using Eq X3.3,
NI_{lf} = value of NI calculated for low fill-factor coils using Eq X3.1 or Eq X3.2, and
Y = ratio of the cross-sectional area of the coil to the cross section of the part. For example, if the coil has an inside diameter of 10 in. (25.4 cm) and part (a bar) has an outside diameter of 5 in. (12.2 cm).

$$Y = (\pi(5)^2)/(\pi(2.5)^2) = 4$$

X3.2.2.3 *High Fill-Factor Coils* In this case, when fixed coils or cable wraps are used and the cross-sectional area of the coil is less than twice the cross-sectional area (including hollow portions) of the part, the coil has a high fill-factor.

(1) For Parts Within a High Fill-Factor Positioned Coil and for Parts with an *L/D* ratio equal to or greater than 3:

$$NI = \frac{K}{\{(L/D) + 2\}}\ (\pm 10\,\%)$$

where:

N = number of turns in the coil or cable wrap,

I = coil current, A,
K = 35 000 (empirically derived constant),
L = part length, in.,
D = part diameter, in., and
NI = ampere turns.

For example, the application of Eq X3.3 can be illustrated as follows: a part 10 in. (25.4 cm) long-with 2-in. (5.08-cm) outside diameter would have an L/D ratio of 5 and an ampere turn requirements of $NI = 35\,000/(5 + 2)$ or 5000 (±10 %) ampere turns. If a five-turn coil or cable wrap is employed, the amperage requirement is 5000/5 or 1000 A (±10 %).

NOTE X3.1—For L/D ratios less than 3, a pole piece (ferromagnetic material approximately the same diameter as part) should be used to effectively increase the L/D ratio or utilize an alternative magnetization method such as induced current. For L/D ratios greater than 15, a maximum L/D value of 15 should be used for all formulas cited above.

X3.2.2.4 *L/D Ratio for a Hollow Piece*
When calculating the L/D ratio for a hollow piece, D should be replaced with an effective diameter D_{eff} calculated using:

$$D_{eff} = 2\left[\left(A_t - A_h\right)/\pi\right]^{1/2}$$

where:

A_t = total cross-sectional area of the part, and
A_h = cross-sectional area of the hollow portion(s) of the part.

$$D_{eff} = \left[(OD)^2 - (ID)^2\right]^{1/2}$$

where:

OD = outside diameter of the cylinder, and
ID = inside diameter of the cylinder.

X4. DEVICES FOR EVALUATION OF MAGNETIC PARTICLE EXAMINATION MATERIALS

X4.1 Scope

X4.1.1 This appendix illustrates several types of devices that can be used to evaluate, or compare the performance of both wet and dry magnetic particle testing materials. Particle performance evaluation devices may be used to: check for material degradation, compare difference materials, check the visibility of any material(s) under varying illumination conditions, and other types of comparisons.

NOTE X4.1—The devices discussed in this section shall not be re-magnetized in any manner or demagnetized in any manner. They contain some form of permanent magnetization. With suitable care, the magnetization within each device should not be subject to change over time.

X4.2 Devices

X4.2.1 *Encoded Magnetic Media*—The magnetic encoding process can generate magnetic gradients in a highly controlled manner. These gradients, when encoded into a media (that is, a magnetic stripe card) can be used as an indicator of magnetic particle performance. Fig. X4.1 illustrates how particles can be attracted to the encoded strip on the magnetic stripe card. For usage information, see X4.3.4.

X4.2.1.1 *Characteristics*—Magnetic stripe cards should be made in accordance with ISO 7810—Identification Cards—Physical Characteristics. The magnetic strip may be made of either low-coercivity (lo-co) or high coercitivty (hi-co) material, as designated by the manufacturer.

X4.2.1.2 *Encoding Pattern*—A constant encoding pattern, decaying encoding patter, reverse decaying pattern, or other pattern may be encoded into the strip. See Fig. X4.1 for a photograph of fluorescent particle indicators of decaying and reverse decaying encoding patterns.

X4.2.2 *Permanently Magnetized Discs*—Cracks in permanently magnetized disks provide the flux leakage required for magnetic particle indications. Observation of the intensity and

FIG. X4.1 Particle indications appear where magnetic gradients have been encoded in the magnetic strip of the card. In this case, the gradients decrease in value from "0" (strongest) to "X" (weakest). Particle performance can be graded on the basis of the weakest indication.

brightness of indication allow a comparison or evaluation of particle performance. Fig. X4.2 illustrates cracks that have been formed in the disk.

X4.2.3 *Permanently Magnetized Blocks*—The seam between two magnetically coupled blocks provide the flux leakage required for magnetic particle indications. The flux density decreases as the distance from the magnet increases and the resulting magnetic particle indication reduces. Fig. X4.3 illustrates how a permanent magnet can be located to result in a particle indication along the seam between two precision formed steel blocks. The seam can be incremented so that the particle performance can be graded.

X4.3 Procedures Considerations

X4.3.1 *Preparation*—The surface of the device must be clean, dry, and free of any particles from previous tests, fluid, or other contaminants or conditions that might interfere with the efficiency of the evaluation prior to the application of the testing material.

X4.3.2 *Device Verification*—Device should be checked with a new material or known material prior to use, to verify the device has not been magnetically altered. If the test indicates the magnetic properties of the device have been altered, it should be replaced. Contact the device manufacturer with regard to any magnetization or performance issues.

X4.3.3 *Equipment and Procedures*—The equipment requirements, test condition and testing procedures for particle evaluation should be established and documented to the extent required in order to provide a standardized evaluation. The requirements may cover such things as UV-A distance and illumination requirements, visible light requirements, particle applicator and application procedure, the use of contrast backgrounds, removal of excess particle and method of documenting results.

NOTE X4.2—Non-fluorescent particle results are particularly impacted by background color. A thin coating simulating test condition background color may be considered in order to provide an additional aid in evaluating particle performance under actual test conditions.

X4.3.4 *Particle Application*—Wet method and dry method materials should be consistent with the method of application that will be used for examinations.

X4.3.4.1 *Wet Method Materials*—Fluorescent or non-fluorescent particles suspended in a liquid vehicle at the required concentration should be applied as they would be used for examination, by gently spraying or flowing the suspension over the area to be examined or by immersion of the device in the suspension. Excess bath shall be allowed to flow away from the device. The device shall be observed under appropriate illumination for the formation of particle indications. Observations shall be noted as to the quality of particle indications and the clarity thereof.

X4.3.4.2 *Dry Method Materials*—Apply dry powder so that a light, uniform, dust-like coating settles on the surface of the device. The applicators should introduce the particles into the air in a manner such that they reach the part surface in a uniform cloud with a minimum of force. Excess particles should be removed by a gentle air current. The device shall be observed under appropriate illumination for the formation of particle indications. Observation shall be noted as to the quality of particle indications and the clarity thereof.

X4.3.5 *Records*—Particle indications may be recorded in accordance with Section 17.

X4.3.6 *Material Noncompliance*—Evaluation of materials not meeting company standard should not be used for examination.

X4.3.7 *Loss of Indications on a Permanently Magnetized Device*—There are several circumstances in which magnetic particle indications may not be visible on the device and when indications are not visible, the subject particles should not be used for examination unless being verified as acceptable using a suitable alternate methodology.

X4.3.7.1 *Concentration*—The subject wet method particles may not have a sufficient level of concentration. In this case, increase the concentration level of the bath and re-perform the check until the particles demonstrate suitable performance.

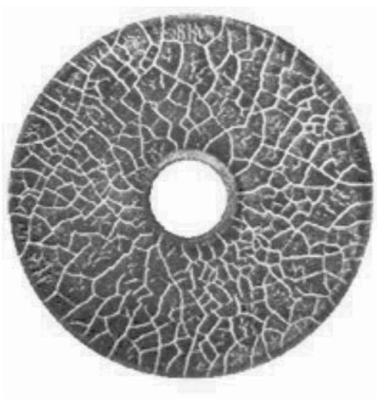


Figure A

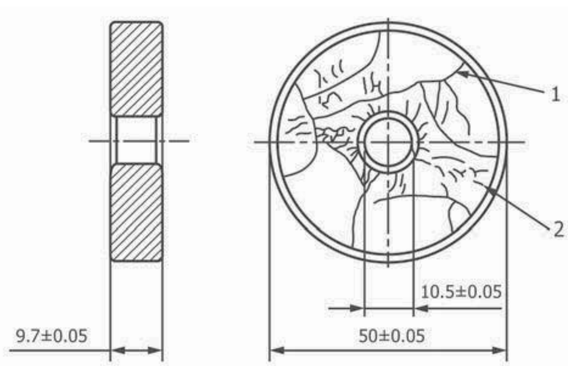


Figure B

FIG. X4.2 Typical dimensions (in millimetres) or a disk containing surface cracks that has been permanently magnetized. In this case, (1) indicates larger cracks formed by grinding and (2) indicates finer cracks caused by stress (induced by quenching).

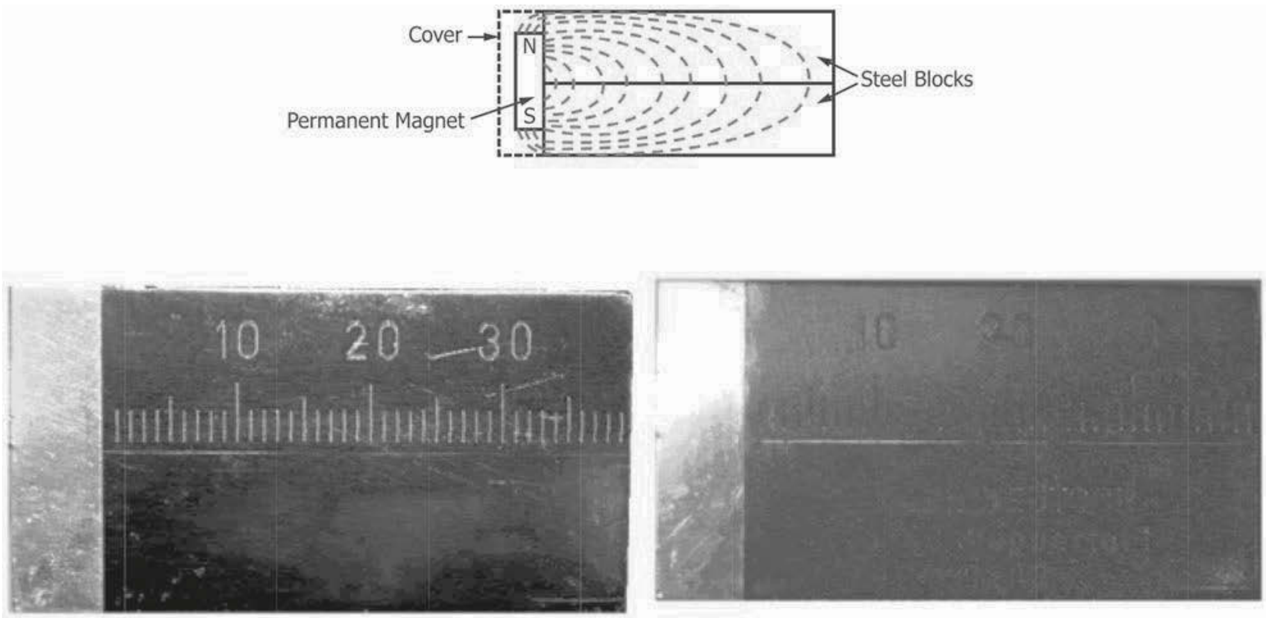


FIG. X4.3 One type of device containing a permanent magnet held next to two precision formed steel blocks with a brass cover. The seam between the steel blocks acts as a discontinuity; particles form an indication on the seam that is strongest close to the magnet and weakens with distance away from the magnet.

X4.3.7.2 *Sensitivity*—The subject particles may not provide necessary sensitivity. In this case, replace the material with a suitably sensitive material and re-perform the check until the particles demonstrate suitable performance.

X4.3.7.3 *Erasure*—The device has become magnetically erased. In this case, no discernible particle indication will appear. Repeat the check with another device, or sensitivity check, or both, until the particles demonstrate suitable performance. Either destroy the device or report it to the manufacturer and follow the manufacturer's recommendations.

X4.3.8 *Handling*—After the visual examination has been made, the surface of the device should be cleaned of remaining fluid and particles in a manner non-detrimental to the device. When not in use, the device should be stored away from excessive heat and strong magnetic fields. Contact the device manufacturer with regard to any magnetization or performance issues.

X5. CENTRIFUGE TUBES

X5.1 Centrifuge tubes should be pear-shaped, made from thoroughly annealed glass, and conform to the dimensions given in Figs. X5.1 and X5.2 as applicable. The graduations, numbered as shown, should be clear and distinct.

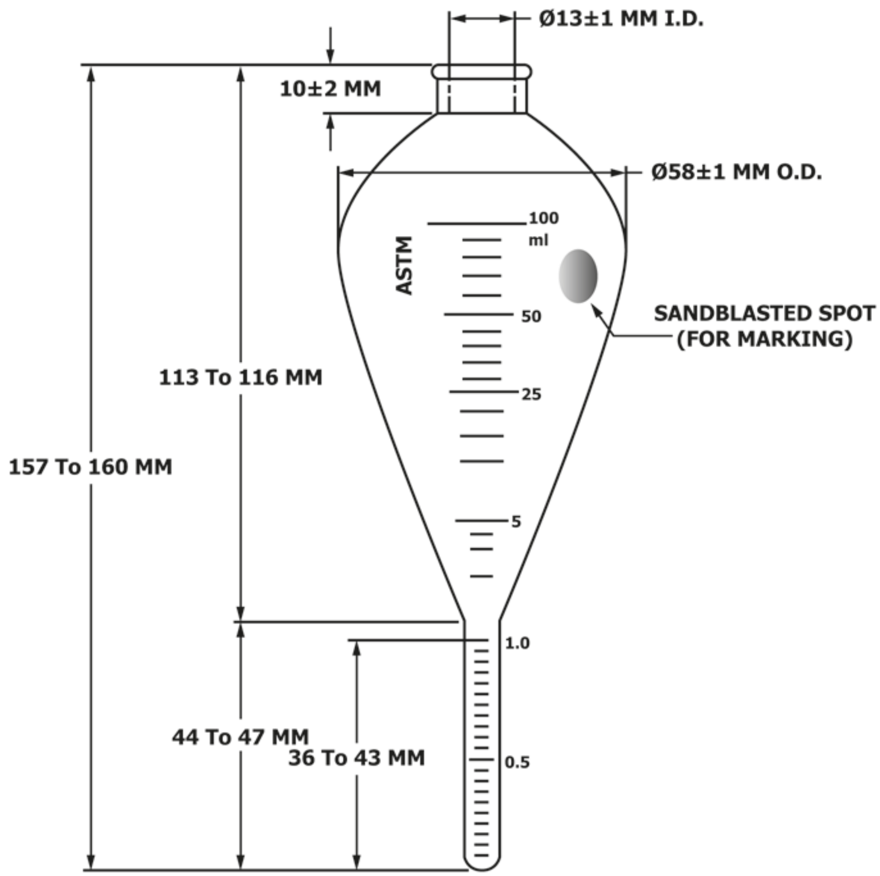


FIG. X5.1 Pear Shaped Centrifuge Tube – Fluorescent Bath

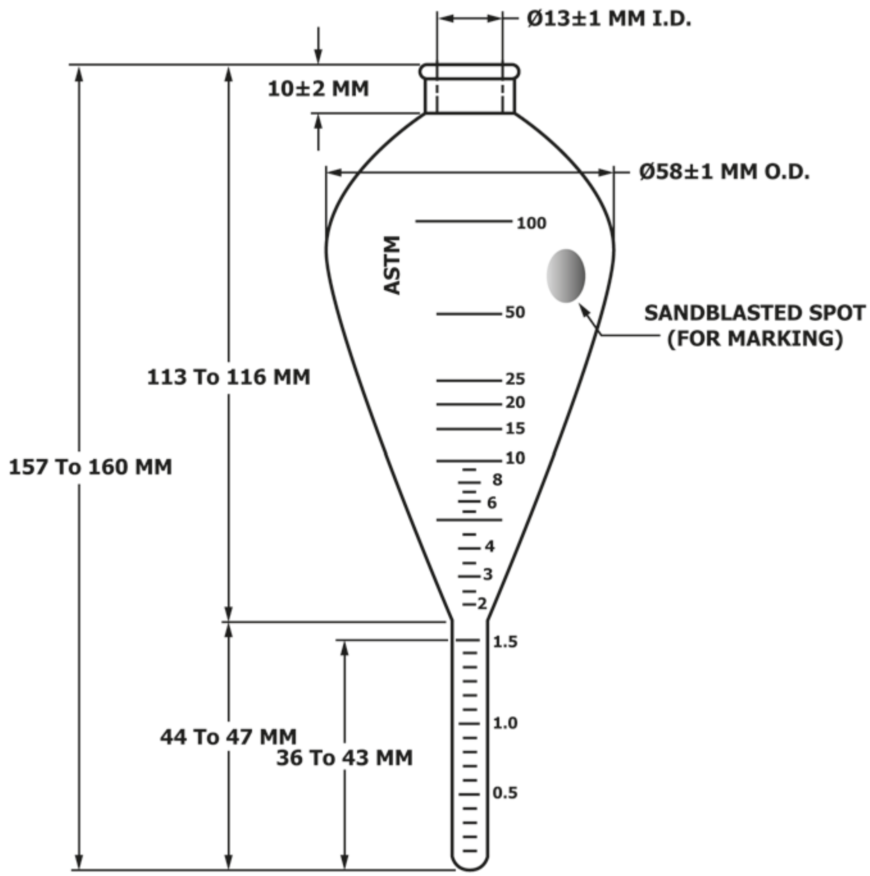


FIG. X5.2 Pear Shaped Centrifuge Tube – Non-Fluorescent Bath

X6. SUITABILITY OF MATERIALS FOR MAGNETIC PARTICLE TESTING

X6.1 Some materials are far more suitable for magnetic particle testing than others. In some cases, liquid penetrant testing may be a more reliable testing method.

X6.2 Some of the precipitation hardening (PH) steels are austenitic in the annealed or low heat treat ranges. Austenitic materials cannot be examined by the magnetic particle testing method.

X6.3 Care must be taken with low permeability steels, such as the PH steels, to use a high enough amperage to provide proper field strength.

X6.4 Steels with very high permeability are easily magnetized but should not be examined with the residual method.

X6.5 Fig. X6.1 is a tabulation of stainless and corrosion resistant steels and their suitability for examination with the magnetic particle testing method.

X6.6 Aluminum and aluminum-based alloys, copper and copper-based alloys, and nickel-based alloys cannot be examined by the magnetic particle testing method.

X6.7 All low-alloy carbon steels, 1000 series (1020, 1050, 1117, 1340, etc.), 4000 series (4130, 4330, 4340M, and so forth), 5000, 6000, 8000, 9000 series, HY 80, HY 100, 9Ni-4Co, and Maraging steels are ferro-magnetic and can be examined with the magnetic particle testing method.

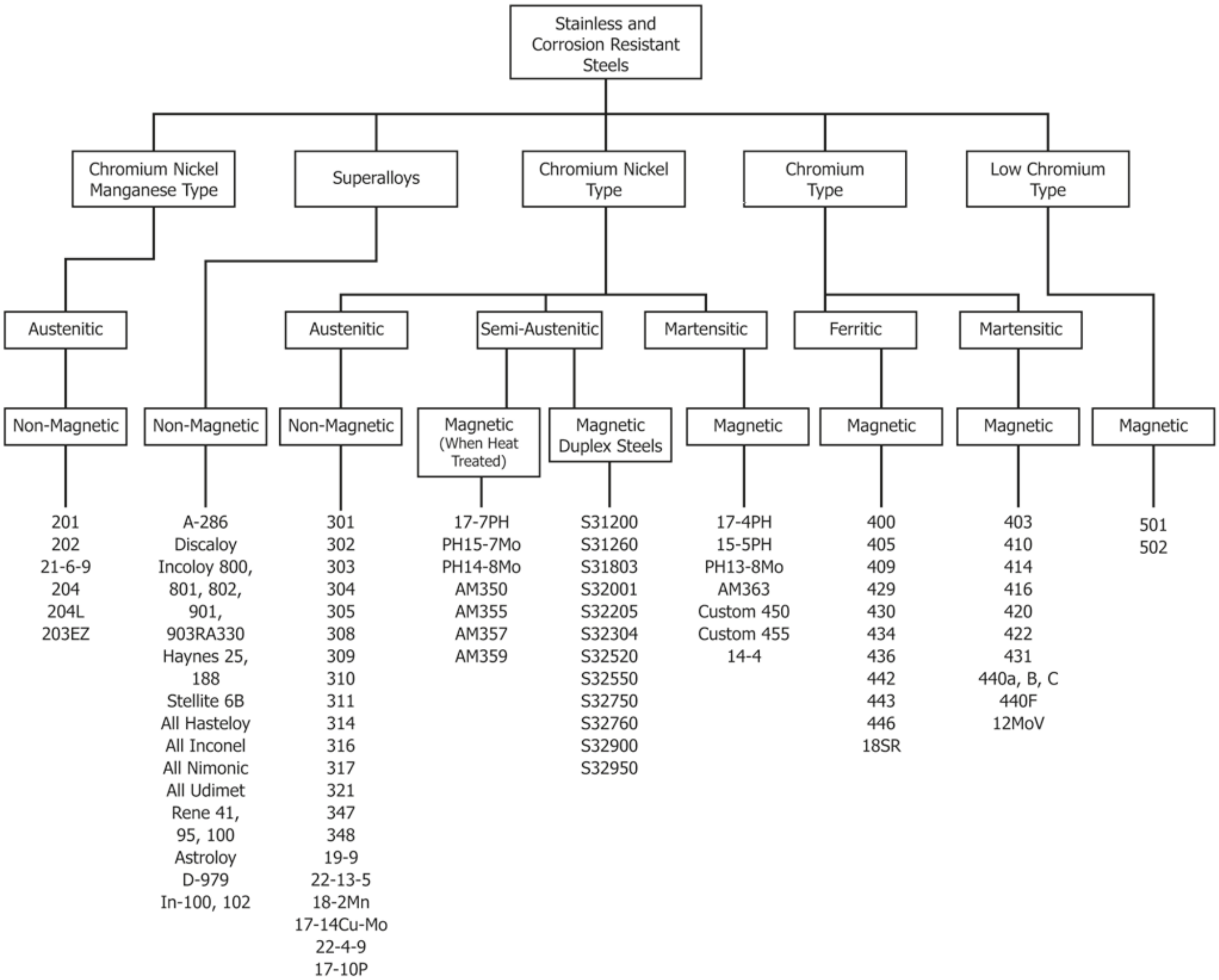


FIG. X6.1 Tabulation of Stainless and Corrosion Resistant Steels

X7. TOOL STEEL RING SPECIMEN FOR SYSTEM PERFORMANCE TEST

X7.1 A ring specimen similar to Fig. X7.1 may be used to perform the system performance verification of X7.2.

X7.2 Wet Particle Test (Conducted in accordance with a written procedure)

X7.2.1 Demagnetize the ring.

X7.2.2 Place a non-ferromagnetic conductor with a diameter between 1.0 and 1.25 in. (25.4 and 31.75 mm) through the center of the ring.

X7.2.2.1 Center the ring on the conductor.

X7.2.3 Magnetize the ring circularly by passing the required current through the conductor. Use the current levels of Table X7.1 or Table X7.2 as applicable to the ring being used.

X7.2.4 Apply the suspension to the ring using the continuous method.

X7.2.5 Examine the ring within 1 min after current application.

X7.2.5.1 Nonflourescent baths shall be examined under visible light of not less than 100 fc (1076 lx).

X7.2.5.2 Flourescent baths shall be examined under black light of not less than 1000 μW/cm^2 and an ambient white light level not greater than 2 fc (22 lx).

X7.2.5.3 The number of hole indications visible shall meet or exceed those specified in Table X7.1 or Table X7.2 as applicable to the ring being used.

X7.2.6 Demagnetize the ring.

X7.3 Dry Particle Test (Conducted in accordance with a written procedure)

X7.3.1 Place a non-ferromagnetic conductor with a diameter between 1.0 and 1.25 in. (25.4 and 31.75 mm) through the center of the ring.

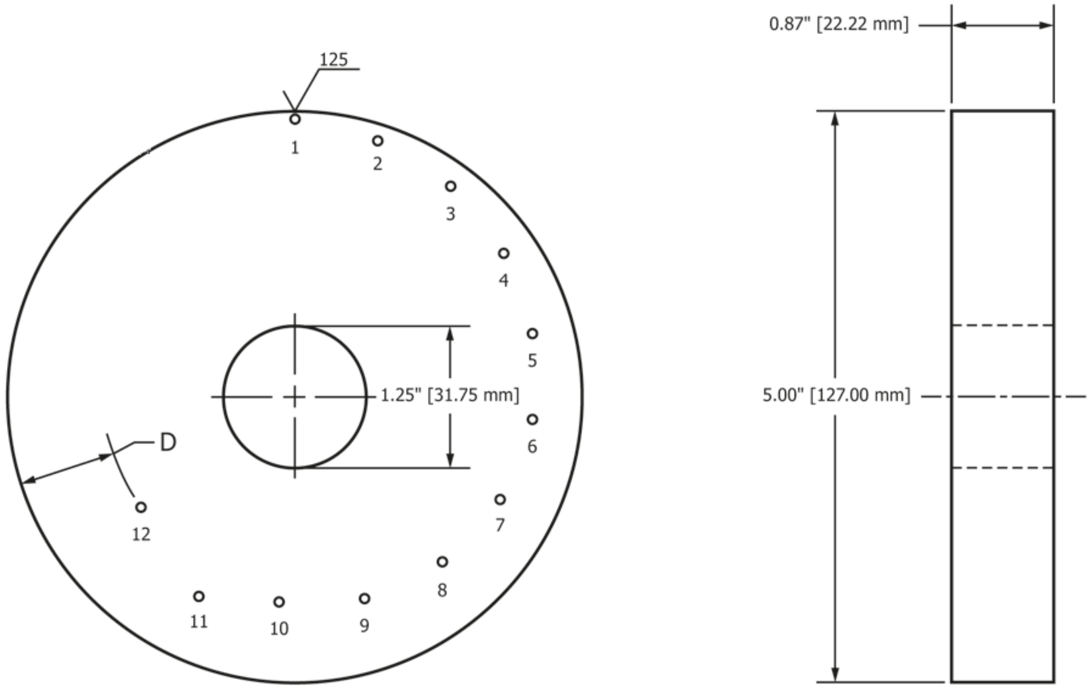


FIG. X7.1 AISI KETOS Tool Steel Ring

Hole[C]	1	2	3	4	5	6
Diameter[A]	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)
"D"[B]	0.07 in. (1.78 mm)	0.14 in. (3.56 mm)	0.21 in. (5.33 mm)	0.28 in. (7.11 mm)	0.35 in. (8.89 mm)	0.42 in. (10.67 mm)

Hole	7	8	9	10	11	12
Diameter[A]	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)	0.07 in. (1.78 mm)
"D"[B]	0.49 in. (12.45 mm)	0.56 in. (14.22 mm)	0.63 in. (16.00 mm)	0.70 in. (17.78 mm)	0.77 in. (19.56 mm)	0.84 in. (21.34 mm)

[A]All hole diameters are ±0.005 in. (±0.13 mm). Rings with holes 10 through 12 are optional.
[B]Tolerance on the D distance is ±0.005 in. (±0.13 mm).
[C]Unless specified, all dimensions are ±0.03 in. (±0.76 mm)

TABLE X7.2 Amperage and Hole Indication Requirements for AS 5282 Rings

Type of Suspension	Amperage FW or HW Rectified	Minimum Number of Holes Indicated
Fluorescent Oxide (Wet)	1000	5
	1500	6
	2500	7
	3500	9
Visible Oxides (Wet)	500	3
	1000	4
	1500	5
	2500	6
	3500	8
Dry Powder	500	4
	1000	6
	1500	7
	2500	8
	3500	9

X7.3.2 Center the ring on the conductor.

X7.3.3 Magnetize the ring circularly by passing the required current through the conductor. Use the applicable current levels of Table X7.1 or Table X7.2 as applicable to the ring being used.

TABLE X7.3 Amperage and Hole Indication Requirements for Ketos 01 Tool Steel Ring Specimen

Type of Suspension	Amperage FW or HW Rectified	Minimum Number of Holes Indicated
Fluorescent Oxide (Wet)	1400	3
	2500	5
	3400	6
Visible Oxides (Wet)	1400	3
	2500	5
	3400	6
Dry Powder	1400	4
	2500	6
	3400	7

X7.3.4 Apply the particles to the ring using a squeeze bulb or other suitable applicator while the current is flowing.

X7.3.5 Examine the ring within 1 min after current application under a minimum of 100 fc (1076 lx) of visible light.

X7.3.5.1 The number of hole indications visible shall meet or exceed those specified in Table X7.1 or Table X7.2, or the written procedure, or both.

X7.3.5.2 Current levels used and number of holes observed may be limited by equipment current capacity.

X7.3.6 Demagnetize the ring.

X8. MAGNETIZATION OF OILFIELD TUBULARS

X8.1 The following requirements should be used to induce residual magnetic fields in oilfield tubulars (tubing, casing, line pipe, and drill pipe).

X8.2 Circular Magnetism

X8.2.1 When capacitor-discharge units are used as magnetizing sources, the oilfield tubulars should be insulated from metal racks and adjacent oilfield tubulars to prevent arc burns.

X8.2.2 Partial demagnetization might occur in a magnetized length of oilfield tubulars if it is not sufficiently separated prior to magnetizing the next adjacent length. The distance used should be at least 36 inches or as determined by the formula I (0.006), whichever is greater, where I is the amperage applied.

X8.2.3 For battery or three-phase rectified-AC power supplies, a minimum magnetizing current of 300 Amps/in of specified outside diameter should be used.

X8.2.4 For full circumference inspection of material with a specified outside diameter of 16 inches and smaller, centralization of the central conductor is not required during magnetization.

X8.2.5 For capacitor-discharge units, see Table X8.1 for magnetizing current requirements.

X8.2.6 The above requirements have been demonstrated by empirical data and do not require verification, however, the amperage should be monitored during current application.

X8.3 Longitudinal Magnetization

X8.3.1 The number of coil turns and current required are imprecise but should not be less than 500 ampere-turns per inch of specified outside diameter. The current should be set as high as possible, but not so high as to cause furring of dry magnetic particles or immobility of wet magnetic particles.

TABLE X8.1 Capacitor Discharge Minimum Current

Number of Pulses	Capacitor Discharge Amperage Requirements	
Single	240 times specified weight per foot in lb/ft	161 times specified weight per metre in kg/m
Double	180 times specified weight per foot in lb/ft	121 times specified weight per metre in kg/m
Triple	145 times specified weight per foot in lb/ft	97 times specified weight per metre in kg/m

ARTICLE 26
EDDY CURRENT STANDARD

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STANDARD PRACTICE FOR ELECTROMAGNETIC (EDDY CURRENT) EXAMINATION OF COPPER AND COPPER-ALLOY TUBES

SE-243

(Identical with ASTM Specification E243-13.)

Standard Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes

1. Scope

1.1 This practice covers the procedures that shall be followed in eddy current examination of copper and copper-alloy tubes for detecting discontinuities of a severity likely to cause failure of the tube. These procedures are applicable for tubes with outside diameters to 3⅛ in. (79.4 mm), inclusive, and wall thicknesses from 0.017 in. (0.432 mm) to 0.120 in. (3.04 mm), inclusive, or as otherwise stated in ASTM product specifications; or by other users of this practice. These procedures may be used for tubes beyond the size range recommended, upon contractual agreement between the purchaser and the manufacturer.

1.2 The procedures described in this practice are based on methods making use of encircling annular examination coil systems.

1.3 *Units*—The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

NOTE 1—This practice may be used as a guideline for the examination, by means of internal probe examination coil systems, of installations using tubular products where the outer surface of the tube is not accessible. For such applications, the technical differences associated with the use of internal probe coils should be recognized and accommodated. The effect of foreign materials on the tube surface and signals due to tube supports are typical of the factors that must be considered. See E690 for additional details regarding the in-situ examinations using internal probes.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B111/B111M Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock

B395/B395M Specification for U-Bend Seamless Copper and Copper Alloy Heat Exchanger and Condenser Tubes

B543 Specification for Welded Copper and Copper-Alloy Heat Exchanger Tube

E543 Specification for Agencies Performing Nondestructive Testing

E690 Practice for In Situ Electromagnetic (Eddy-Current) Examination of Nonmagnetic Heat Exchanger Tubes

E1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

NAS-410 NAS Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)

3. Terminology

3.1 *Definitions of Terms Specific to this Standard*

3.1.1 The following terms are defined in relation to this standard.

3.1.1.1 *artificial discontinuity reference standard*—a standard consisting of a selected tube with defined artificial discontinuities, used when adjusting the system controls to obtain some predetermined system output signal level. This standard may be used for periodic checking of the instrument during an examination.

3.1.1.2 *percent maximum unbalance standardization standard*—a method of standardization that can be used with speed-insensitive instruments (see 3.1.1.4). The acceptance level of the examination is established at the operating examination frequency as an accurate fraction of the maximum unbalance signal resulting from the end effect of a tube. Any low-noise tube from the production run having a squared end may be used as this standard. This standard may be used for periodic checking of the instrument during an examination.

3.1.1.3 *electrical center*—the center established by the electromagnetic field distribution within the examination coil. A constant-intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the examination coil.

3.1.1.4 *speed-sensitive equipment*—examination equipment that produces a variation in signal response with variations in the examination speed. Speed-insensitive equipment provides a constant signal response with changing examination speeds.

3.1.1.5 *off-line examining*—eddy current examinations conducted on equipment that includes the examination coil and means to propel individual tubes under examination through the coil at appropriate speeds and conditions.

3.1.1.6 *on-line examining*—eddy current examinations conducted on equipment that includes the examination coil and means to propel tubes under examination through the coil at appropriate speeds and conditions as an integral part of a continuous tube manufacturing sequence.

3.2 *Definitions of Terms*—Refer to Terminology E1316 for definitions of terms that are applicable to nondestructive examinations in general.

4. Summary of Practice

4.1 Examining is usually performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity and magnetic permeability of the tube material, and metallurgical or mechanical discontinuities in the tube. During passage of the tube, the changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

5. Significance and Use

5.1 Eddy current testing is a nondestructive method of locating discontinuities in a product. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the walls. Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated defects decreases.

5.2 Some indications obtained by this method may not be relevant to product quality; for example, a reject signal may be caused by minute dents or tool chatter marks that are not detrimental to the end use of the product. Irrelevant indications can mask unacceptable discontinuities. Relevant indications are those which result from nonacceptable discontinuities. Any indication above the reject level that is believed to be irrelevant shall be regarded as unacceptable until it is demonstrated by re-examination or other means to be irrelevant (see 10.3.2).

5.3 Eddy current testing systems are generally not sensitive to discontinuities adjacent to the ends of the tube (end effect). On-line eddy current examining would not be subject to end effect.

5.4 Discontinuities such as scratches or seams that are continuous and uniform for the full length of the tube may not always be detected.

6. Basis of Application

6.1 *Personnel Qualification*—Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, NAS-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the purchase specification or contractual agreement between the using parties.

NOTE 2—MIL-STD-410 is canceled and has been replaced with NAS-410, however, it may be used with agreement between contracting parties.

6.2 *Qualification of Nondestructive Testing Agencies*—If specified in the purchase specification or contractual agreement, NDT agencies shall be evaluated and qualified as described in Practice E543. The applicable edition of Practice E543 shall be identified in the purchase specification or contractual agreement between the using parties.

7. Apparatus

7.1 *Electronic Apparatus*—The electronic apparatus shall be capable of energizing the examination coil with alternating currents of suitable frequencies (for example, 1 kHz to 125 kHz), and shall be capable of sensing the changes in the electromagnetic response of the coils. Electrical signals produced in this manner are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

7.2 *Examination Coils*—Examination coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube. The examination coil diameter should be selected to yield the largest practical fill-factor.

7.3 *Driving Mechanism*—A mechanical means of passing the tube through the examination coil with minimum vibration of the examination coil or the tube. The device shall maintain the tube substantially concentric with the electrical center of the examination coil. A uniform speed (± 5.0 % speed variation maximum) shall be maintained.

7.4 *End Effect Suppression Device*—A means capable of suppressing the signals produced at the ends of the tube. Individual ASTM product specifications shall specify when an end effect suppression device is mandatory.

NOTE 3—Signals close to the ends of the tube may carry on beyond the limits of end suppression. Refer to 9.5.

8. Reference Standards

8.1 *Artificial Discontinuity Reference Standard:*

8.1.1 The tube used when adjusting the sensitivity setting of the apparatus shall be selected from a typical production run and shall be representative of the purchaser's order. The tubes shall be passed through the examination coil with the instrument sensitivity high enough to determine the nominal background noise inherent in the tubes. The reference standard shall be selected from tubes exhibiting low background noise. For on-line eddy current examining, the reference standard is created in a tube portion existent in the continuous manufacturing sequence or in other forms as allowed by the product specification.

8.1.2 The artificial discontinuities shall be spaced to provide signal resolution adequate for interpretation. The artificial discontinuities shall be prepared in accordance with one of the following options:

(a) A round bottom transverse notch on the outside of the tube in each of three successive transverse planes at 0, 120, and 240° (Fig. 1).

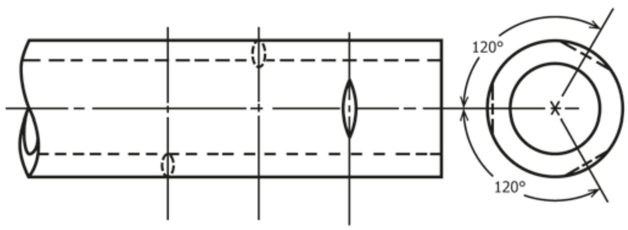


FIG. 1 Reference Standard with Three Notches

(b) A hole drilled radially through the tube wall in each of three successive transverse planes at 0, 120, and 240° (Fig. 2).

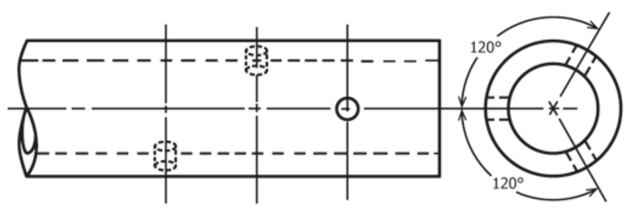


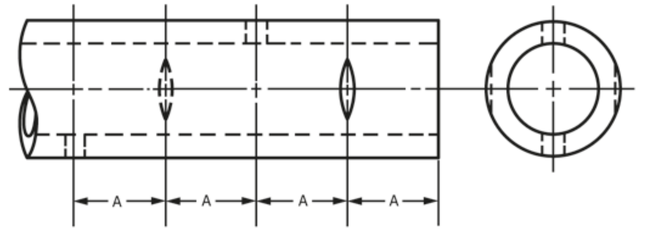
FIG. 2 Reference Standard with Three Holes

(c) One round bottom transverse notch on the outside of the tube at 0° and another at 180°, and one hole drilled radially through the wall at 90° and another at 270°. Only one notch or hole shall be made in each transverse plane (Fig. 3).

(d) Four round bottom transverse notches on the outside of the tube, all on the same element of the tube (Fig. 4).

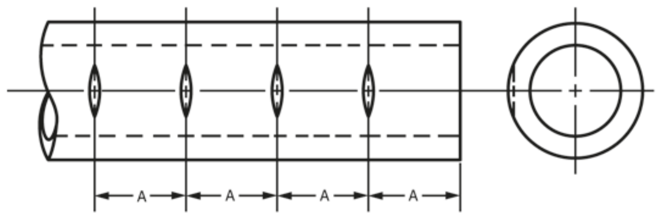
(e) Four holes drilled radially through the tube wall, all the same element of the tube (Fig. 5).

8.1.2.1 *Round Bottom Transverse Notch*—The notch shall be made using a suitable jig with a 0.250-in. (6.35-mm) diameter No. 4 cut, straight, round file. The outside surface of the tube shall be stroked in a substantially straight line perpendicular to the axis of the tube. The notch depth shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary from the notch depth by more than ±0.0005 in. (±0.013 mm) when measured at the center of the notch (see Table X1.1).[6]



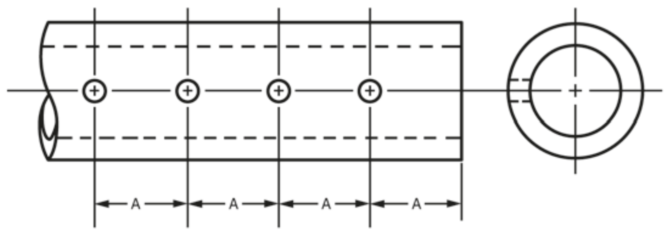
NOTE 1—A = Space to provide signal resolution adequate for interpretation.

FIG. 3 Reference Standard with Two Notches and Two Holes



NOTE 1—A = Space to provide signal resolution adequate for interpretation.

FIG. 4 Reference Standard with Four Notches in Line



NOTE 1—A = Space to provide signal resolution adequate for interpretation.

FIG. 5 Reference Standard with Four Holes in Line

NOTE 4—Tables X1.1 and X1.2 should not be used for acceptance or rejection of materials.

8.1.2.2 *Drilled Holes*—The hole shall be drilled radially through the wall using a suitable drill jig that has a bushing to guide the drill, care being taken to avoid distortion of the tube while drilling. The drilled hole diameter shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary by more than +0.001, −0.000 in. (+0.026 mm) of the hole diameter specified (see Table X1.2) (Note 4).

8.1.2.3 *Other Artificial Discontinuities*—Discontinuities of other contours may be used in the reference standard by mutual agreement between supplier and purchaser.

8.2 *Percent Maximum Unbalance Reference Standard*—This method of standardization shall be used only with speed-insensitive equipment, and equipment specifically designed or adapted to accommodate the use of this calibration method. Maximum unbalance of differential coils is obtained by placing the squared end of a tube in only one of the differential coils and using an accurately calibrated attenuator to obtain the (100 %) maximum unbalance signal. A percentage of the maximum unbalance signal shall define the examination acceptance level at a specific operating frequency and this percentage shall be obtained from the ASTM product specification.

8.3 *Other Reference Standards*—Other reference standards may be used by mutual agreement between supplier and purchaser.

NOTE 5—Artificial discontinuities and the percent of maximum unbalance are not intended to be representative of natural discontinuities or produce a direct relationship between instrument response and discontinuity severity; they are intended only for establishing sensitivity levels as outlined in Section 9. The relationship between instrument response and discontinuity size, shape, and location is important and should be established separately, particularly as related to examination frequency.

9. Adjustment and Standardization of Apparatus Sensitivity

9.1 The tube manufacturer shall select equipment, reference standard, and examination parameters consistent for the product, unless otherwise agreed upon between manufacturer and purchaser.

9.2 When using the artificial discontinuity reference standard, prepared in accordance with one of the five options, adjust the apparatus to the lowest sensitivity required to detect the following:

9.2.1 For Figs. 1-3: all artificial discontinuities in the standard. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.2.2 For Figs. 4 and 5: a minimum of two of the four artificial discontinuities as the tube is rotated by 120°- intervals through 0, 120, and 240°, or by 90°- intervals through 0, 90, 180, and 270° on successive passes. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.3 When using the percent maximum unbalance reference standard, adjust the apparatus to the percent unbalance called for in the ASTM product specification.

NOTE 6—Sensitivity control settings are usually indicated by arbitrary numbers on the control panel of the testing instruments. These numerical settings differ among instruments of different types. It is, therefore, not proper to transfer numerical settings on one instrument to those of another instrument, unless the percent maximum unbalance reference standard is used. Even among instruments of the same design and from the same manufacturer, sensitivity control settings may vary. Undue emphasis on the numerical value of sensitivity control settings is not justified and shall not be used unless referenced accurately to the maximum unbalance signal.

9.4 Discard and replace the tube used as the reference standard when erroneous signals are produced from mechanical, metallurgical, or other damage to the standard.

9.5 Determine the length of tubing requiring suppression of end effect signals by selecting a tube of low background noise and making a series of reference holes or notches at 0.5-in. (12.7-mm) intervals near the end of this special tube. Pass the tube through the examination coil at the production examination speed with the artificial discontinuities end first, and then with the artificial discontinuities end last. Determine the distance from the tube end at which the signal response from successive discontinuities is uniform with a recording device such as a pen recorder or memory oscilloscope. Use a signal suppression method (photo relay, mechanical switches, or proximity devices are commonly used) to permit examining only when the length of tubing exhibiting uniform signals is within the examination coil. The section of tube passing through the examination coil during end effect suppression is not examined in accordance with 9.2 or 9.3.

9.5.1 As an option to 9.5, when a recording device is not available, the length of tubing requiring end suppression may be determined by selecting a tube of low background noise and making a reference hole or notch at 6 to 8 in. (152 to 203 mm) from the tube end. Pass the tube through the examination coil at the production examination speed with the artificial discontinuity end first and then with the artificial discontinuity end last. If the artificial discontinuity is not detected, another artificial discontinuity should be made further from the end. If it is detected, cut off 0.5-in. (12.7-mm) increments from the end of the tube until the artificial discontinuity is no longer detected. The shortest distance from the end that the artificial discontinuity can be detected is that length of tube which shall require end effect signal suppression.

10. Procedure

10.1 Electrically center the tubing in the examination coil at the start of the examination run. The tube manufacturer may use the artificial discontinuity reference standard or prepare a separate tube for this purpose in accordance with 8.1 and 8.2. Pass the tube through the examination system and mechanically adjust its position in the examination coil such that the requirements of 9.2 are satisfied.

10.2 Standardize the examination system at the start of the examination run and at periodic intervals (for example, every 2 h) of continuous operation or whenever improper functioning of the system is suspected.

10.3 Pass the tubes through the examination system standardized as described in Section 9.

10.3.1 Accept those tubes that produce output signals conforming to the limits in the applicable ASTM product specification.

10.3.2 Tubes that produce output signals not conforming to the limits in the applicable ASTM product specification may, at the option of the manufacturer, be set aside for re-examination (see 5.2). Upon re-examination, accept the tubes if the output signals are within acceptable limits (10.3.1) or demonstrated by other re-examination to be irrelevant.

10.4 Tubes may be examined at the finish size after the final anneal or heat treatment, or at the finish size prior to the final anneal or heat treatment unless otherwise agreed upon between the supplier and the purchaser.

11. Keywords

11.1 electromagnetic (eddy current) testing; NDT; nondestructive testing; copper; tubing

APPENDIX

(Nonmandatory Information)

X1. TABLES

TABLE X1.1 Notch Depth

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over 1/4 to 3/4, incl	Over 3/4 to 1 1/4, incl	Over 1 1/4 to 3 1/8, incl
Over 0.017–0.032	0.005	0.006	0.007
Incl 0.032–0.049	0.006	0.006	0.0075
Incl 0.049–0.083	0.007	0.0075	0.008
Incl 0.083–0.109	0.0075	0.0085	0.0095
Incl 0.109–0.120	0.009	0.009	0.011

Tube Wall Thickness, mm	Tube Outside Diameter, mm		
	Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 79, incl
Over 0.43–0.61	0.13	0.15	0.18
Incl 0.81–1.3	0.15	0.15	0.19
Incl. 1.3–2.1	0.18	0.19	0.20
Incl. 2.1–2.8	0.19	0.22	0.24
Incl. 2.8–3.0	0.23	0.23	0.28

TABLE X1.2 Diameter of Drilled Holes

Tube Outside Diameter	Diameter of Drilled Holes	Drill No.
in.	in.	
1/4 to 3/4, incl	0.025	72
Over 3/4 –1, incl	0.031	68
Over 1–1 1/4, incl	0.036	64
Over 1 1/4 –1 1/2, incl	0.042	58
Over 1 1/2 –1 3/4, incl	0.046	56
Over 1 3/4 –2, incl	0.052	55

Tube Outside Diameter	Diameter of Drilled Holes	Drill No.
mm	mm	
6.0–19.0, incl	0.635	72
Over 19.0–25, incl	0.785	68
Over 25–32, incl	0.915	64
Over 32–38, incl	1.07	58
Over 38–45, incl	1.17	56
Over 45–50, incl	1.32	55

ARTICLE 29
ACOUSTIC EMISSION STANDARDS

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STANDARD GUIDE FOR MOUNTING PIEZOELECTRIC ACOUSTIC EMISSION SENSORS

(19) SE-650/SE-650M

(Identical with ASTM Specification E650/E650M-17.)

Standard Guide for
Mounting Piezoelectric Acoustic Emission Sensors

1. Scope

1.1 This document provides guidelines for mounting piezoelectric acoustic emission (AE) sensors.

1.2 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bonding agent*—a couplant that physically attaches the sensor to the structure.

3.1.2 *couplant*—a material used at the structure-to-sensor interface to improve the transfer of acoustic energy across the interface.

3.1.3 *mounting fixture*—a device that holds the sensor in place on the structure to be monitored.

3.1.4 *sensor*—a detection device that transforms the particle motion produced by an elastic wave into an electrical signal.

3.1.5 *waveguide, acoustic*—a device that couples acoustic energy from a structure to a remotely mounted sensor. For example, a solid wire or rod, coupled to a sensor at one end and to the structure at the other.

3.2 *Definitions:*

3.2.1 For definitions of additional terms relating to acoustic emission, refer to Terminology E1316.

4. Significance and Use

4.1 The methods and procedures used in mounting AE sensors can have significant effects upon the performance of those sensors. Optimum and reproducible detection of AE requires both appropriate sensor-mounting fixtures and consistent sensor-mounting procedures.

5. Mounting Methods

5.1 The purpose of the mounting method is to hold the sensor in a fixed position on a structure and to ensure that the acoustic coupling between the sensor and the structure is both adequate and constant. Mounting methods will generally fall into one of the following categories:

5.1.1 *Compression Mounts*—The compression mount holds the sensor in intimate contact with the surface of the structure through the use of force. This force is generally supplied by springs, torqued-screw threads, magnets, tape, or elastic bands. The use of a couplant is strongly advised with a compression mount to maximize the transmission of acoustic energy through the sensor-structure interface.

5.1.2 *Bonding*—The sensor may be attached directly to the structure with a suitable adhesive. In this method, the adhesive acts as the couplant. The adhesive must be compatible with the structure, the sensor, the environment, and the examination procedure.

6. Mounting Requirements

6.1 *Sensor Selection*—The correct sensors should be chosen to optimally accomplish the AE examination objective. Selection parameters to be considered are as follows: size, sensitivity, frequency response, surface-motion response, environmental compatibility, background noise, source location requirements, and material properties of the structure under examination. When a multichannel acoustic-emission examination is being conducted, a subset of sensors with characteristics similar to each other should be selected. See Guide E976 for methods of comparing sensor characteristics.

6.1.1 If the examination objective is to include AE source location, sensor selection may be governed by the material properties of the structure and may affect subsequent sensor spacing due to attenuation. It may be necessary to evaluate attenuation effects as part of the pre-examination procedure. If performed, the attenuation data shall be retained as part of the experimental record.

6.1.2 When a multichannel acoustic-emission examination is being conducted, a subset of sensors with characteristics similar to each other should be selected. See Guide E976 for methods of comparing sensor characteristics.

6.2 *Structure Preparation*—The contacting surfaces should be cleaned and mechanically prepared. This will enhance the detection of the desired acoustic waves by assuring reliable coupling of the acoustic energy from the structure to the sensor. Preparation of these surfaces must be compatible with the construction materials used in both the sensor and the structure. Possible losses in acoustic energy transmission caused by coatings such as paint, encapsulants, loose-mill scale, weld spatter, and oxides as well as losses due to surface curvature at the contact area must be considered.

6.2.1 The location of each sensor should be measured and marked accordingly on the structure and recorded as part of the examination record.

6.2.2 If surface preparation requires removing paint from a metal surface, the paint may be removed with a grinder or other mechanical means, down to bare metal. The area of paint removal should be slightly larger than the diameter of the sensor. If the metal surface is smooth, sandpaper may be used to roughen the surface prior to bonding.

6.2.2.1 After paint removal, the surface should be cleaned with a degreaser and wiped clean with a cloth.

6.2.2.2 If corrosion is present on the structure, additional cleaning may include using a conditioner (mild acid) and neutralizer to minimize potential corrosion beneath the sensor after mounting.

6.2.2.3 If the structure is located in a marine environment, soluble salts (e.g. chlorides, nitrates, sulfates) may still reside on the steel surface even after cleaning. These types of salts attract moisture from the air, and may result in additional corrosion beneath the sensor and failure of the bond. As such, a liquid soluble salt remover is recommended as an additional step in surface preparation prior to sensor mounting.

6.3 *Couplant or Bonding Agent Selection:*

6.3.1 The type of couplant or bonding agent should be selected with appropriate consideration for the effects of the environment (for example, temperature, pressure, composition of gas, or liquid environment) on the couplant and the constraints of the application. It should be chemically compatible with the structure and not be a possible cause of corrosion. In some cases, it may be a requirement that the couplant be completely removable from the surface after examination. In general, the selection of the couplant is as important from an environmental standpoint as it is from the acoustical standpoint.

6.3.2 For sensors that are primarily sensitive to particle motion perpendicular to their face, the viscosity of the couplant is not an important factor. Most liquids or greases will work as a couplant if they wet the surfaces of both the structure and the sensor. For those few sensors which are sensitive primarily to motion in the plane of their face, very high-viscosity couplant or a rigid bond is recommended.

6.3.2.1 Testing has shown that in most cases, when working at frequencies below 500 kHz, most couplants will suffice. However, due to potential loss of high frequency (HF) spectra when working above 500 kHz, a low viscosity couplant or rigid bond, relative to sensor motion response, is recommended. Additionally, when spectral response above 500 kHz is needed, it is recommended that FFT be performed to verify adequacy of HF response.

6.3.3 The thickness of the couplant may alter the effective sensitivity of the sensor. The thinnest practical layer of continuous couplant is usually the best. Care should be taken that there are no entrapped voids in the couplant. Unevenness, such as a taper from one side of the sensor to the other, can also reduce sensitivity or produce an unwanted directionality in the sensor response.

6.3.4 A useful method for applying a couplant is to place a small amount of the material in the center of the sensor face, then carefully press the sensor on to the structure surface, spreading the couplant uniformly from the center to the outside of the sensor face. Typically, this will result in a small band (fillet) of couplant around the outside circumference of the sensor.

6.3.5 In some applications, it may be impractical to use a couplant because of the nature of the environment (for example, very high temperatures or extreme cleanliness requirements). In these situations, a dry contact may be used, provided sufficient mechanical force is applied to hold the sensor against the structure. The necessary contact pressure must be determined experimentally. As a rough guide, this pressure should exceed 0.7 MPa [100 psi].

6.3.6 Great care must be taken when bonding a sensor to a structure. Surface deformation, that can be produced by either mechanical loading or thermal expansion, may cause a bond to crack, peel off, or, occasionally, destroy the sensor. Bond cracking is a source of acoustic emission. A pliant adhesive may work in some cases. If differential expansion between the sensor, the bond, and the surface is a possibility, a suitable bonding agent should be confirmed by experiment.

6.3.7 When bonding agent are used, the possibility of damaging either the sensor or the surface of the structure during sensor removal must be considered.

6.3.7.1 To minimize damage to the sensor during removal, any excess bonding agent may be gently removed from around the base of the sensor using a small chisel and hammer or mallet. Place a small block of wood, or the handle of the chisel, at the base of the sensor. Using a hammer or mallet gently tap the side of the block or handle to generate a shear force at the base of the sensor to break the bond. Attempting to pry or twist off the sensor by hand, or striking the side of the sensor at the top will often cause the ceramic face or wear plate of the sensor to debond from the sensor housing and destroy the sensor.

6.3.7.2 Any bonding agent remaining on the face of the sensor after removal may be gently chipped off or removed with a grinder at low speed to avoid damage to the wear plate.

6.3.8 The use of double-sided adhesive tape as a bonding agent is not recommended.

6.4 *Mounting Fixture Selection:*

6.4.1 Mounting fixtures must be constructed so that they do not create extraneous acoustic emission or mask valid acoustic emission generated in the structure being monitored.

6.4.1.1 The mount must not contain any loose parts of particles.

6.4.1.2 Permanent mounting may require special techniques to prevent sensor movement caused by environmental changes.

6.4.1.3 Detection of surface waves may be suppressed if the sensor is enclosed by a welded-on fixture or located at the bottom of a threaded hole. The mounting fixture should always be designed so that it does not block out a significant amount of acoustic energy from any direction of interest.

6.4.2 The mounting fixture should provide support for the signal cable to prevent the cable from stressing the sensor or the electrical connectors. In the absence of a mounting fixture, some form of cable support should be provided. Care should be taken to ensure that the cable can neither vibrate nor be moved easily. False signals may be generated by the cable striking the structure and by triboelectric effects produced by cable movement.

6.4.3 Where necessary, protection from the environment, such as encapsulation, should be provided for the sensor or sensor and mounting fixture.

6.4.4 The mounting fixture should not affect the integrity of the structure being monitored.

6.4.4.1 Permanently installed mounting fixtures must be constructed of a material compatible with the structure. Possible electrolytic effects or other forms of corrosion must be considered when designing the mounting fixture.

6.4.4.2 Alterations of the local environment by the mount, such as removal of the insulation, must be carefully evaluated and corrected if necessary.

6.4.5 The mounting fixture should be designed to have a minimal effect on the response characteristics of the sensor.

6.4.6 Mounting fixtures and waveguides should be designed to provide isolation of the sensor case from the fixture or waveguide that is in contact with the structure to avoid grounding the sensor to the structure ground, especially those sensors that use an isolated sensor face (e.g epoxy or ceramic face). Failure to isolate the sensor will result in a ground loop and will create a significant amount of electrical noise in the AE system and may mask detection of the AE activity of interest.

6.5 *Waveguides*—When adverse environments make direct contact between the sensor and the structure undesirable, an acoustic waveguide may be used to transmit the acoustic signal from the structure to the sensor. The use of a waveguide adds another boundary transition with its associated losses between the structure and the sensor, and will distort, to some degree, the characteristics of the acoustic wave.

6.5.1 An acoustic waveguide should be mounted to ensure that its surface will not contact any materials that will cause signal damping in the waveguide.

6.5.2 If acoustic waveguides are used when acoustic-emission source location is being performed, the extra time delay in the waveguides must be accounted for in the source location program.

7. Verification of Response

7.1 After the sensor(s) are mounted on a structure, adequate response should be verified by injecting acoustic signals into the structure and examining the detected signal either on an oscilloscope or with the AE system to be used in the examination. If there is any doubt as to the sensor response, the sensor should be remounted.

7.1.1 The test signal may be injected by an external source such as the Hsu-pencil source, or a gas jet (helium or other suitable gas), or by applying an electrical pulse to another sensor mounted on the structure. For a description of these methods see Guide E976.

7.2 *Periodic Verification*—On an extended acoustic emission examination, it may be desirable to verify the response of the sensors during the examination. Verification should be performed whenever circumstances indicate the possibility of a change in the coupling efficiency.

7.3 *Post Verification*—At the end of an acoustic emission examination, it is good practice to verify that all sensors are still working and that there have been no dramatic changes in coupling efficiencies.

8. Report

8.1 Any report of the mounting practice should include details of the sensor mounting fixture(s), surface preparation method, and the couplant that was used.

9. Keywords

9.1 acoustic emission; acoustic emission sensors; acoustic emission transducers; AE; bonding agent; couplant; mounting fixture; waveguide

STANDARD PRACTICE FOR CHARACTERIZING ACOUSTIC EMISSION INSTRUMENTATION

SE-750

(Identical with ASTM Specification E750-10.)

Standard Practice for Characterizing Acoustic Emission Instrumentation

1. Scope

1.1 This practice is recommended for use in testing and measuring operating characteristics of acoustic emission electronic components or units. (See Appendix X1 for a description of components and units.) It is not intended that this practice be used for routine checks of acoustic emission instrumentation, but rather for periodic evaluation or in the event of a malfunction. The sensor is not addressed in this document other than suggesting methods for standardizing system gains (equalizing them channel to channel) when sensors are present.

1.2 Where the manufacturer provides testing and measuring details in an operating and maintenance manual, the manufacturer's methods should be used in conjunction with the methods described in this practice.

1.3 The methods (techniques) used for testing and measuring the components or units of acoustic emission instrumentation, and the results of such testing and measuring should be documented. Documentation should consist of photographs, screenshots, charts or graphs, calculations, and tabulations where applicable.

1.4 AE systems that use computers to control the collection, storage, display, and data analysis, might include waveform collection as well as a wide selection of measurement parameters (features) relating to the AE signal. The manufacturer provides a specification for each system that specifies the operating range and conditions for the system. All calibration and acceptance testing of computer-based AE systems must use the manufacturer's specification as a guide. This practice does not cover testing of the computer or computer peripherals.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E1316 Terminology for Nondestructive Examinations

2.2 *ANSI Standard:*

ANSI/IEEE 100-1984 Dictionary of Electrical and Electronic Terms

2.3 *Other Documents:*

Manufacturer's Operating and Maintenance Manuals pertinent to the specific instrumentation or component

3. Terminology

3.1 *Definitions*—For definitions of additional terms relating to acoustic emission, refer to Terminology E1316.

4. Summary of Practice

4.1 Tests and measurements should be performed to determine the instrumentation bandwidth, frequency response, gain, noise level, threshold level, dynamic range, signal overload point, dead time, and counter accuracy.

4.2 Where acoustic emission test results depend upon the reproduced accuracy of the temporal, spatial, or spectral histories, additional measurements of instrumentation parameters should be performed to determine the specific limits of instrumentation performance. Examples of such measurements may include amplifier slew rate, gate window width and position, and spectral analysis.

4.3 Tests and measurements should be performed to determine the loss in effective sensor sensitivity resulting from the capacitive loading of the cable between the preamplifier and the sensor. The cable and preamplifier should be the same as that used for the acoustic emission tests without substitution. (See also Appendix Appendix X2.)

4.3.1 Important tests of a computer-based AE system include the evaluation of limits and linearity of the available parameters such as:

(*a*) Amplitude,

(*b*) Duration,

(*c*) Rise Time,

(*d*) Energy, and

(*e*) AE Arrival Time.

4.3.2 The processing speed of these data should be measured as described in 7.4.3 for both single- and multiple-channel operation.

4.3.3 The data storage capability should be tested against the specification for single- and multiple-channel operation. Processing speed is a function of number of channels, parameters being measured, timing parameter settings, AE signal duration, front-end filtering, storage device (RAM, disk), and on-line analysis settings (number of graphs, data listings, location algorithms, and more). If waveform recording is used, this may influence the processing speed further.

5. Significance and Use

5.1 This practice provides information necessary to document the accuracy and performance of an Acoustic Emission system. This information is useful for reference purposes to assure that the instrumentation performance remains consistent with time and use, and provides the information needed to adjust the system to maintain its consistency.

5.2 The methods set forth in this practice are not intended to be either exclusive or exhaustive.

5.3 Difficult or questionable instrumentation measurements should be referred to electronics engineering personnel.

5.4 It is recommended that personnel responsible for carrying out instrument measurements using this practice should be experienced in instrumentation measurements, as well as all the required test equipment being used to make the measurements.

6. Apparatus

6.1 The basic test instruments required for measuring the operating characteristics of acoustic emission instrumentation include:

6.1.1 *Variable Sine Wave Generator or Oscillator,*

6.1.2 *True RMS Voltmeter,*

6.1.3 *Oscilloscope,*

6.1.4 *Variable Attenuator, graduated in decibels*, and

6.1.5 *Tone Burst Generator.*

6.2 Additional test instruments may be used for more specialized measurements of acoustic emission instrumentations or components. They are as follows:

6.2.1 *Variable-Function Generator,*

6.2.2 *Time Interval Meter,*

6.2.3 *Frequency Meter, or Counter,*

6.2.4 *Random Noise Generator,*

6.2.5 *Spectrum Analyzer,*

6.2.6 *D-C Voltmeter,*

6.2.7 *Pulse-Modulated Signal Generator,*

6.2.8 *Variable Pulse Generator,* and

6.2.9 *Phase Meter,*

6.2.10 *Electronic AE Simulator* (or an Arbitrary Waveform Generator (AWG) can be used providing an automated evaluation).

6.3 An electronic AE simulator (or AWG) is necessary to evaluate the operation of computer-based AE instruments. A detailed example of the use of an electronic AE simulator (or AWG) is given in 7.4.3 under dead time measurement. The instruction manual for the electronic AE simulator provides details on the setup and adjustment of the simulator. Control of pulse frequency, rise time, decay, repetition rate, and peak amplitude in the simulator makes it possible to simulate a wide range of AE signal conditions.

7. Measurement Procedure

7.1 *Frequency Response and Bandwidth Measurements:*

7.1.1 The instrumentation, shown in Fig. 1, includes the preamplifier with amplification and signal filters, possibly connected to the AE system which might have additional signal filters, amplification, and interconnecting cables. All measurements and tests should be documented. If the preamplifier is to be tested without the AE system connected, it should be terminated with the normal working load as shown on the bottom right of Fig. 1.

7.1.2 An acceptable frequency response should be flat between cutoff frequencies within 3 dB of the reference frequency. The reference frequency is the geometric mean of

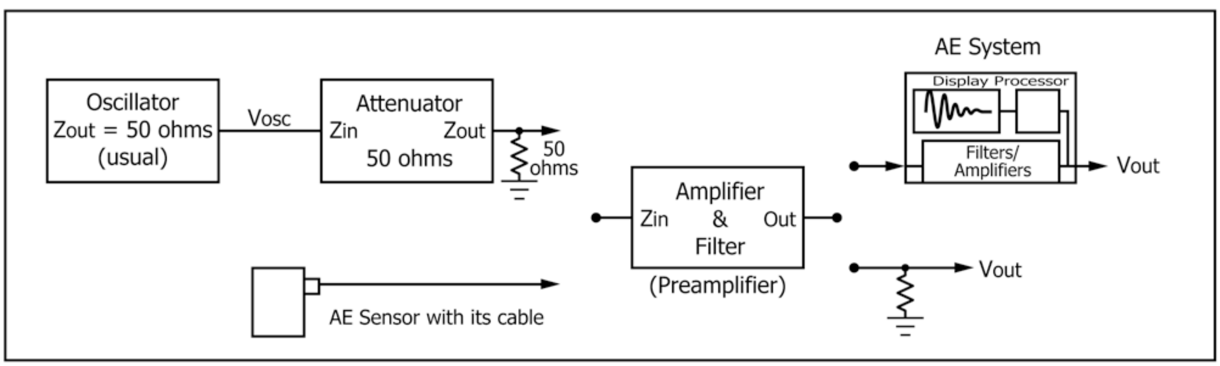

FIG. 1 Component Configuration Used for Testing and Measuring the Frequency Response, Amplification, Noise, Signal Overload, Recovery Time, and Threshold of Acoustic Emission Instrumentation

the nominal bandwidth of the instrumentation. The mean frequency is calculated as follows:

$$f_M = (f_L f_H)^{\frac{1}{2}}$$

where:

f_M = mean frequency,
f_L = nominal lower cutoff, and
f_H = nominal upper cutoff.

7.1.3 The bandwidth should include all contiguous frequencies with amplitude variations as specified by the manufacturer. Instruments that include signal processing of amplitude as a function of frequency should have bandwidth amplitude variations as specified by the manufacturer.

7.1.4 With the instrumentation connected to the oscillator and attenuator, see Fig. 1 and the sine wave oscillator set well within the instrumentation's specified dynamic range, the frequency response should be measured between frequency limits specified in 7.1.2. The oscillator is maintained at a fixed amplitude and the frequency is swept through the frequency limits. The preamplifier or AE system voltage output is monitored with an RMS voltmeter. Values of amplitude are recorded for each of several frequencies within and beyond the nominal cutoff frequencies. The recorded values should be plotted. The amplitude scale may be converted to decibels. The frequency scale may be plotted either linearly or logarithmically. Appendix X2 provides further discussion of wave shaping components.

7.1.5 A spectrum analyzer may be used in conjunction with a white noise source or an oscilloscope may be used in conjunction with a sweep frequency oscillator to determine bandwidth. With a white noise source connected to the input, a spectrum analyzer connected to the output will record the frequency response.

7.1.6 The measured bandwidth is the difference between the corner frequencies at which the response is 3 dB less than the response at the reference frequency.

7.2 *Gain Measurements:*

7.2.1 The electronic amplification is comprised of the preamplifier gain, the wave filters insertion gains or losses and the AE system's gains or losses. (See Appendix X2 for an explanation of gain measurements.)

7.2.2 The electronic amplification may be measured with the test setup shown in Fig. 1, with the oscillator and attenuator connected. The sine wave oscillator is set to the reference frequency. The oscillator amplitude is set well within the dynamic range of the instrumentation to avoid distortion due to overload. With the voltmeter at V_{osc}, oscillator amplitude is set to 1 V. The attenuator is set for a value greater than the anticipated electronic amplification. Next, the voltmeter is moved to V_{out} (preamplifier or AE system voltage output depending on the test being performed). The attenuator is now adjusted until the voltmeter again reads 1 V. The electronic amplification is equal to the new setting on the attenuator. A white noise generator or sweep generator and spectrum or FFT analyzer may be used in place of the oscillator and RMS voltmeter.

NOTE 1—If the input impedance of the preamplifier is not both resistive and equal to the required load impedance of the attenuator, proper compensation should be made.

7.3 *Dynamic Range Measurements:*

7.3.1 The criterion used for establishing dynamic range should be documented as the signal overload point, referenced to the instrumentation noise amplitude, while keeping like measurements for both readings (for example, peak voltage to peak voltage, peak-peak voltage or RMS to RMS readings). Alternatively, the reference amplitude may be the threshold level if the instrumentation includes a voltage comparator for signal detection. The total harmonic distortion criterion should be used for signal processing involving spectrum analysis. All other signal processing may be performed with the signal overload point criterion.

7.3.2 The dynamic range (DR) in decibels should be determined as follows:

$$DR = 20\log_{10}(\text{signal overload point voltage/background noise voltage})$$

7.3.2.1 The dynamic range of instrumentation exclusive of threshold or voltage comparator circuits, is a ratio of the signal overload level to the noise amplitude. (A brief description of noise sources appears in Appendix X4). An oscilloscope is usually required as an adjunct to determine the characteristics of noise and to monitor the signal overload point.

7.3.2.2 A field measurement of dynamic range may produce substantially different results when compared with a laboratory measurement. This difference is caused by an increase in the reference voltage output, and may result from noise impulses of electrical origin, or ground faults.

7.3.2.3 For an amplifier that has a threshold comparator as its output device, the dynamic range is the ratio of maximum threshold level to input noise level at the comparator. Excess amplitude range in the amplifier contributes to overload immunity but not to the dynamic range. The following measurement will give the effective dynamic range:

$$DR_e = 20\log_{10}(\text{MaxTh/MinTh})$$

where:

DR_e = the effective dynamic range of the system,
MaxTh = the highest settable threshold value that just passes the largest undistorted peak signal input, and
MinTh = the threshold value that passes less than 1 count/s with no input signal.

This dynamic range is the difference between the largest and the smallest AE input that can be reliably detected by the system.

7.3.3 Measurement of instrument electronic noise is accomplished by replacing the oscillator/attenuator of Fig. 1, with the sensor that will be used, including its cable (or with a lumped equivalent capacitance). A lumped capacitance represents the electrical characteristic of the sensor and cable combination without adding mechanical noise interference. The RMS noise voltage is measured with a true RMS voltmeter (see 6.1.2) at the instrumentation (preamplifier or AE system) output (V_{out}) per Fig. 1. Alternatively, a peak AE system noise measurement can be measured by setting the lowest possible AE threshold which passes less than one false hit within ten seconds or by setting the AE system threshold below the noise and recording the peak AE amplitude of hits detected in a ten second period.

7.3.4 The signal overload level is measured by replacing the sensor with the sine wave oscillator as shown in Fig. 1. The frequency is set to the mid-band frequency of the instrumentation. The oscillator amplitude is fixed at 1 V peak to peak monitored at V_{osc}. The attenuator is adjusted to increase the signal level to the preamplifier until the instrumentation output (V_{out}) is 0.5 dB less than the computed output.

7.3.5 Should the peak amplitude of acoustic emission activity exceed the dynamic range, several deleterious effects may be produced; these include clipping, saturation, and overload recovery time-related phenomena. (See Appendix X2 for a discussion of overload recovery.) The instrumentation gain should be adjusted to limit these effects to an absolute minimum in order to increase the reliability of the data.

7.4 *Dead Time Measurements:*

7.4.1 The instrumentation dead time may include variable and fixed components, depending on the instrumentation design for handling the routine of the input and output data processing. The components included in dead time are process time and lock-out time. Process time varies from system to system and usually depends on the number of parameters processed for each AE hit. Lock-out time, which may be operator controlled, is used to force a time delay before accepting new AE hits.

7.4.2 Dead time measurement in a counter type AE instrument should be conducted as follows: Set the instrument to the count rate mode. Set the oscillator frequency to the mid-band frequency of the instrument. Set the oscillator amplitude to achieve a count rate equal to the oscillator frequency. Increase the oscillator frequency until the count rate ceases to equal the oscillator frequency. Record the frequency as the maximum count rate. (If the frequency is equal to or greater than the specified upper frequency limit of the instrument, the dead time of the counter is zero.) Dead time (*Td*) is given by:

$$Td = 1/Fm - 1/Fu$$

where:

Fm = the measured frequency, and
Fu = the upper bandwidth limit of the instrument.

7.4.3 Where the dead time in question is related to AE hit processing such as measurement of source location, energy, duration, or amplitude, the measurement is best accomplished by using an electronic AE simulator as follows:

7.4.3.1 Select an AE hit parameter to evaluate the dead time.

7.4.3.2 Set the electronic AE simulator frequency, rise, decay, duration, and repetition rate such that the observed AE hit rate in the selected parameter equals the repetition rate of the simulator.

7.4.3.3 Increase the repetition rate of the simulator until the observed AE hit rate falls below the simulator rate.

7.4.3.4 Record this value as maximum AE hit rate (processing speed) for the selected parameter.

7.4.4 The dead time (*Td*) is given by:

$$Td = 1/R_B - D_B$$

where:

D_B = the selected burst duration, and
R_B = the repetition rate of the simulator where the limit was found.

This dead time measurement procedure should be performed for each AE hit-based parameter of the AE system.

7.5 *Threshold Level (Threshold of Detection) Measurements:*

7.5.1 Various acoustic emission signal processing instruments rely upon the signal exceeding a comparator voltage level to register a hit. This level may be fixed, adjustable, floating and fixed, or floating and adjustable. The floating threshold may be called automatic threshold. Signal recognition (or hit) does not occur until the threshold is exceeded.

7.5.2 The nonautomatic threshold level should be measured with the instrumentation assembled as shown in Fig. 1 and the signal processors attached to the point V_{out}. The signal processors are frequently digital electronic counters that may follow the secondary amplifier. Increasing the oscillator amplitude will result in an increasing signal level at V_{out}. The counters will begin counting when the signal at the comparator reaches the preset threshold level. This level measured with an oscilloscope connected to V_{out} multiplied by the gain of the secondary amplifier is equal to the threshold voltage. Some counters and other signal processors utilizing threshold detection are frequency sensitive. Therefore, the threshold level should be measured over the instrumentation bandwidth.

7.5.3 The automatic threshold cannot be measured with a continuous-wave generator because the automatic threshold level is usually derived from the rectified and averaged input signal. The tone burst generator provides an adjustable burst amplitude duration and repetition rate that may be used to establish the threshold level using the same technique that is used in 7.5.2. The automatic threshold level's affected by the tone burst amplitude, duration, and repetition rate.

7.6 *Counter Accuracy Measurements:*

7.6.1 Counters are of two types: summation counters and rate counters. Counters that tally signals for fixed repetitive periods of time during an acoustic emission test are known as rate counters. The tallied signals may be a count of acoustic emission signals, loading cycles, or amplitude levels.

7.6.2 The accuracy of the counting function of the instrumentation should be measured using a tone burst generator set as follows: (1) the amplitude should be well above the threshold level, but well within the dynamic range of the instrumentation; (2) the tone burst frequency should be within the instrumentation nominal bandwidth; (3) the tone burst duration should be at least one cycle, but fewer cycles than would cause the automatic threshold to take effect; (4) the tone burst repetition rate should be adjusted for a period that does not cause the automatic threshold to interfere with the count function. The counting accuracy is assured by comparing the emission count with the tone burst count.

7.7 *Computer-Measured Parameters:*

7.7.1 The limits and linearity of AE parameters recorded by computer-based systems may be measured by means of an electronic AE simulator. The electronic AE simulator provides individually adjustable amplitude, duration, rise time, and relative arrival time. Burst energy from the AE simulator may be calculated from the parameters given.

7.7.2 The limits or dynamic range and linearity of each parameter should be measured as follows for amplitude, duration, and rise time:

7.7.2.1 Connect the AE simulator to the preamplifier input of the channel to be tested.

7.7.2.2 Set up the AE system to record and display the parameter to be tested.

7.7.2.3 Adjust the AE simulator to produce a mid range simulated AE signal where the displayed amplitude, duration, and rise time are 10 % of their maximum value as specified by the AE system manufacturer.

7.7.2.4 Record the value of each parameter at the electronic AE simulator output and at the AE system display.

7.7.2.5 To measure upper limits for each parameter, increase the measured input in equal increments (for example, 10 % of maximum) and record the displayed value for that parameter until the output differs from the input by 10 % or the specified maximum value is exceeded.

7.7.2.6 To measure lower limits for each parameter, adjust input-output condition as in 7.7.2.3, then decrease the input in equal increments (for example, 10 % of the initial value) and record the displayed value until the output differs from the input by 10 % or the minimum value specified by the AE system manufacturer is reached.

7.7.2.7 To test the computer-derived energy per AE hit parameter, it is necessary to calculate the input energy from the electronic AE simulator in accordance with the method used by the AE system. For example, one method used in some AE systems computes approximate burst pulse AE hit energy (E) as follows:

$$E \cong DV^2/2$$

where:

D = burst duration, and
V = peak amplitude.

7.7.2.8 Set the initial conditions as in 7.7.2.3. Increment input amplitude to obtain approximately 10 % of full scale change in energy input. Record the displayed energy per AE hit value at each increment until the output differs from the input by 10 % or the maximum value specified by the AE system manufacturer is exceeded. Repeat this process with amplitude fixed at the initial value while incrementing pulse duration.

7.7.2.9 Again repeat the process with amplitude and pulse duration except decrease each parameter until the minimum value specified by the manufacturer is reached or no further change in the output is produced.

7.7.3 The source location computational algorithm is a complex computer process not covered by this document. However, a multichannel electronic AE simulator may be used to check the location accuracy of systems that rely on the constancy of sound velocity to calculate location. For anisotropic materials where velocity is not constant, other source location algorithms exist such as area location based on first hit sensor.

7.7.3.1 Set up the AE system for source location in accordance with the operator's manual.

7.7.3.2 Set up the multichannel electronic AE simulator to provide simulated AE inputs to the appropriate number of channels.

7.7.3.3 Using the appropriate velocity of sound for the simulated structure, compute the times of flight from the simulated AE source position to each sensor of the source location array. The differences between the times of flight give relative arrival times (delta T) for the simulated AE sensor positions.

7.7.3.4 Record the displayed location coordinates for this initial simulated input. Compute and input a new delta T set for a nearby point. Record the difference between input position and displayed position. Continue this incremental movement of the simulated AE source away from the sensor array center until the output position differs from the input position by 10 % or the source location range specified by the AE system manufacturer is exceeded. Evaluate any error with respect to the AE system manufacturer's specification for source location linearity.

7.7.3.5 The source location test procedure should be repeated for two additional rays extending in different directions from the array center.

7.7.3.6 The source location procedure should be repeated for each multichannel array of the system.

8. Keywords

8.1 acoustic emission; AE; dead-time; gain; preamplifier; sensitivity; sensor; signal processor; threshold

APPENDIXES

(Nonmandatory Information)

X1. DESCRIPTION OF AE INSTRUMENT COMPONENTS

X1.1 *Acoustic Emission Instrumentation*—Acoustic emission electronic components or units should include the sensor(s), preamplifier(s), filter(s), power amplifier(s), line drive amplifier(s), threshold and counting instrumentation, and signal cables. The sensitivity calibration and transfer characteristics of sensors are excluded from this standard.

X1.2 *Acoustic Emission Sensor:*

X1.2.1 An acoustic emission sensor is an electro-acoustic transducer that converts stress wave energy into electrical energy.

X1.2.2 A transformer or amplifier, or acoustic waveguide, if combined with the sensor in such a way that the readily accessible terminals include these components should be considered part of the sensor and the term "sensor" should apply to the combination.

X1.2.3 Sensors may be designed with different active elements including magnetostrictive, electromagnetic, eddy current, capacitive, piezoresistive, piezoelectric, photoacoustic, or acoustoelectric devices. These may be assembled in single-ended or differential configuration with directional properties.

X1.2.4 The most frequently used sensor is the piezoelectric type contained within a conductive housing. The active face is often fitted with a nonconductive, machinable wear plate or shoe. An electrical connector mounted to the housing completes the sensor.

X1.3 *Acoustic Emission Preamplifier:*

X1.3.1 The acoustic emission preamplifier is the first amplifier following the sensor. The preamplifier power may be supplied by the secondary amplifier, or directly from the power mains. The preamplifier is defined as the first stage of amplification with the major function of converting the sensor impedance to an impedance suitable for driving long signal cables and additional electronic components or units.

X1.3.2 The input impedance of a preamplifier forms the load for the sensor. The proper magnitude and phase angle of the input impedance is governed by the sensor requirements. Inductive sensors may require relatively low impedance loads. Capacitive sensors generally require high impedance loads. The low impedance loads depend upon current (or power) drive and the high impedance loads depend upon voltage (or charge) drive. Because the most commonly used sensor is a piezoelectric device, the preamplifier input impedance is moderately high.

X1.3.3 The output impedance of acoustic emission preamplifiers is low, usually about 50 ohms. This low impedance is required to drive long cables and reduce the susceptibility to coupled noise currents.

X1.3.4 The acoustic emission preamplifier may include filters and input/output line transformers. Filters are often employed to reject undesirable signals and avoid potentially overdriven stages within the preamplifier and succeeding components or units. Transformers are used for matching impedances between the source and its load. Transformers are also used for matching balanced to unbalanced transmission lines.

X1.4 *Acoustic Emission Signal Processor:*

X1.4.1 The signal processor provides the final, required instrumentation amplification. This amplifier must supply sufficient signal power to supply a combination of additional components or units such as oscilloscopes, voltmeters, counters, and recorders. For this reason, the secondary amplifier is often called a power amplifier. Additional bandpass filtering is often employed in this amplifier.

X1.4.2 The input impedance of the secondary amplifier should provide the required load impedance for the preceding component. The preceding component is usually the preamplifier, but may be a bandpass filter.

X1.4.3 The secondary amplifier should be used within its stated nominal operating range. The amplifier should complement the operating characteristics of the preceding component.

X1.4.4 The secondary amplifier may also include signal processing circuits such as an RMS voltage converter and an event counting circuit.

X1.5 *Filter:*

X1.5.1 A filter separates signals on the basis of frequency. It introduces relatively small loss to waves in one or more frequency bands and relatively large loss to waves of other frequencies.

X1.5.2 Filters may be active or passive. Active filters require electrical power. Passive filters require no electrical power.

X1.5.3 The most frequently used filter is the bandpass filter. A bandpass filter is a filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency. The gain at the cutoff frequencies should be 3 dB less than the passband geometric mean (reference) frequency as defined in 7.1.2. The slope of the filter characteristic outside the passband is very important for rejection of extraneous signals. Slopes of 30 dB per octave are typical for AE instruments.

X1.5.4 The filter should not limit the specified signal overload point of the preceding component or unit.

X1.5.5 AC-coupled amplifiers and preamplifiers limit the bandwidth by circuit design. Typical bandwidths may extend from a low of 1 KHz to a high of 2 MHz.

X1.6 *Line-Drive Amplifiers:*

X1.6.1 Where extremely long coaxial cables must be used, line-drive amplifiers are normally used. The line-drive amplifier is primarily an impedance conversion device. Line-drive amplifiers are used to supply sufficient signal current to drive several hundred metres of coaxial cable.

X1.6.2 The output impedance of a line-drive amplifier should be the same as the impedance of the coaxial cable that it drives, and the cable should terminate in its characteristic impedance for minimum reflection at the termination and for maximum power transfer.

X1.6.3 The dynamic range, signal overload point, and spectral response of the line-drive amplifier should be equal to or greater than those of the preceding component or unit unless otherwise specifically stated in report documentation.

X1.7 *Counting Instrumentation-Threshold Crossing:*

X1.7.1 Counting of threshold crossings is one of the most frequently used signal processing techniques for acoustic emission. This technique requires the signal amplitude to exceed a threshold voltage or comparator level to be recognized and recorded. Counting is often performed in two ways: rate and summation counting. The accuracy of rate counting depends upon the accuracy of the clock frequency. The accuracy of rate and summation counting depends upon the stability of the threshold level.

X1.7.2 The threshold level may be fixed, manually variable, automatic floating, or a combination thereof, depending upon the design and user application.

X1.7.3 Counters are designed to accept signals that exceed some threshold voltage or comparator level. Upon counting to some maximum count, some counters will reset to zero and begin again, while others will latch at the maximum value. The counters may be manually resettable, and may include an electrical circuit permitting the counter to be reset by a periodic electrical, or clock, signal.

X2. EXPLANATION OF SUGGESTED MEASUREMENTS

X2.1 *Preamplifier Input Impedance:*

X2.1.1 The preamplifier input impedance should be documented as the nominal input impedance. The preferred expression of input impedance should be a stated value of resistance shunted by a stated value of capacitance (see Appendix X3).

X2.1.2 Where inductive coupling is used, the input impedance should be documented in either the polar or rectangular form of its equivalent impedance as a function of frequency over the designed bandwidth of the preamplifier.

X2.1.3 Where charge amplifiers are used for acoustic emission amplification, the manufacturer's specification should suffice to describe the input impedance for direct-coupled piezoelectric generators. Any modification of the input impedance and the precise change of that impedance should be documented.

X2.2 *Input Coaxial Cables:*

X2.2.1 The coaxial cable, coupling the piezoelectric/capacitive sensor to the preamplifier, together with the cable couplings should be measured with a bridge (1.0 KHz) to determine the line capacitance. Visual examination of the cable should ensure that there is no damage to the line and connection. It is sometimes useful to know, with some precision, the capacitances of the sensor element and the connecting cable with its connectors, and the preamplifier input shunt capacitance in order to adjust sensitivity by appropriately increasing or decreasing shunt capacitance. Efforts to lower capacitance shunting the sensor will be rewarded by improved signal-to-noise ratios.

X2.2.2 The line capacitance should be documented and added to the preamplifier capacitance. The sum of line capacitance and preamplifier input capacitance should be documented as the sensor load capacitance for piezoelectric and capacitive sensors.

X2.2.3 Where the system to preamplifier cable is used also to supply a voltage to the preamplifier, the cross coupling between the signal lines and power supply lines might affect the detection of the AE.

X2.2.4 The influence of the coaxial cable and preamplifier impedance on the sensor open circuit sensitivity should be understood regardless of the sensor, cable, and preamplifier type or design.

X2.3 *Wave Shaping:*

X2.3.1 Acoustic emission instrumentation often contains electrical circuits that modify the applied waveform through a predictable and expected process. Such circuits are defined as wave-shaping circuits. Wave-shaping circuits include delayed action circuits, integrators, differentiators, and envelope circuits. These circuits are often found in instrumentation with floating threshold and event counters. The number and function of wave-shaping circuits likely to be found in acoustic emission instrumentation are too numerous to be listed within this practice.

X2.3.2 The characteristics of wave-shaping circuits of interest should include rise time, duration, and decay time. The measurement of these characteristics depends upon the circuit design. The manufacturer should provide the temporal data and the test methods and measurement of these data in the operating and maintenance manual supplied with the component or unit.

X2.3.3 There are numerous sources for error in the measurement of instrumentation characteristics. These include impedance matching of signal sources to instrument inputs, frequency bandpass asymmetry, and windowing problems in spectrum analysis. The examples of error sources are mentioned to alert the user to the fact that a multichannel AE system should be characterized by comparing parameters channel to channel in order to minimize differences.

X2.4 *Gain Measurement:*

X2.4.1 A sensor being acted upon by a stress that generates an electrical signal can be modeled as a two-terminal black box containing an impedance in series with a generator of EMF. The impedance is primarily capacitive and, in the absence of a physical excitation, the substitution of a stable oscillating signal provides a suitable representation for the transduced EMF.

X2.4.2 Channel-to-channel sensitivity or gain can be measured and adjusted easily using a technique known as voltage insertion calibration which takes advantage of this model. A simple voltage insertion box is shown schematically in Fig. X2.1. Fig. X2.2 shows the equivalent circuit of the voltage insertion measurement.

X2.4.3 In this technique a calibrating voltage is inserted in series with the sensor and the channel gain is adjusted so that all channels in the system yield the same output level for the same oscillator input. This will assure that all channels will produce the same output for the same physical excitation if it were possible to reproduce the same physical excitation for each channel.

X2.4.4 The calibration voltage is chosen to be any convenient value near that expected from an acoustic emission event of interest, taking into account the dynamic range expected from the data.

X2.4.5 The frequency of the calibration voltage should be selected to be well below the resonances of the AE sensors, which are presumed to be of the resonant (undamped) type, but within the band pass of the AE system. This will prevent the individual resonances, which may be different from channel to channel, from influencing the gain adjustments.

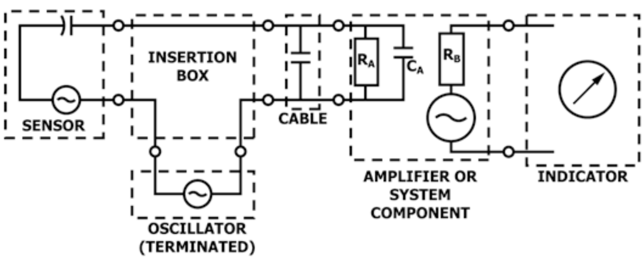

FIG. X2.2 Equivalent Circuit of the Voltage Insertion Measurement

X2.4.6 If the oscillator is calibrated and terminated, a known signal can be applied and the effective gain of the system with cables and sensor can be measured with an indicator on the channel output such as an RMS voltmeter.

X2.5 *Overload Recovery Time:*

X2.5.1 Overload recovery time results from exceeding the dynamic range in a limited number of older instruments. The time required to recover from an acoustic emission event whose amplitude exceeds the dynamic range depends upon the amplifier and instrumentation design, and current instruments should have overload recovery times less than one microsecond.

X2.5.2 The recovery time should be measured with an oscilloscope and a tone burst generator. The tone burst generator replaces the oscillator shown in Fig. X2.1 and the oscilloscope is connected to V_{out}. The tone burst generator is set between the geometric mean frequency and the nominal lower cutoff frequency. The tone burst should be a simple rectangular burst at the selected frequency. The duration of the tone burst is set for the duration expected from the acoustic emission events. Unless otherwise restricted and stated, the amplitude should be set for 2v peak to peak. The tone burst should have a repetition time in excess of the instrumentation recovery time such that instrumentation recovery should occur in less time than the next tone burst would occur. The oscilloscope should record the signal at V_{out} such that the residual feed-through from the tone burst generator may be observed following the tone burst and instrumentation overload recovery. The instrumentation overload recovery time is the time from the end of the tone burst to the time at which the residual has returned to its quiescent value (usually 1 % of the tone burst amplitude). A waveform synthesizer may be substituted for the tone burst generator, but provision should be made to allow measurement of residual amplitude between bursts.

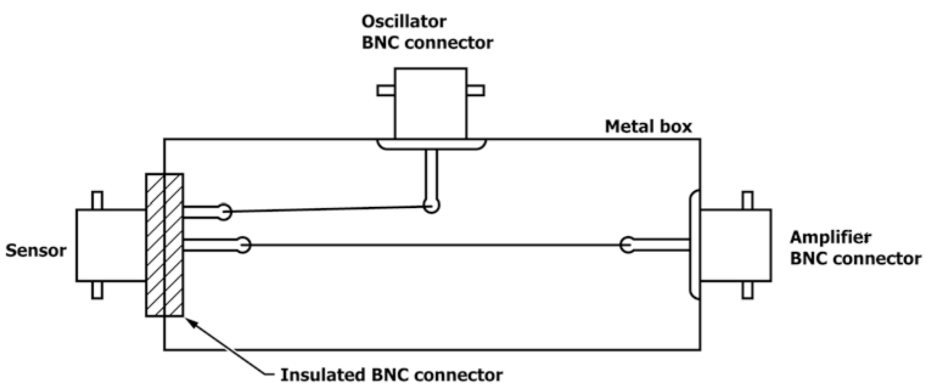

FIG. X2.1 Schematic of a Simple Voltage Insertion Box

X3. MEASUREMENT OF INPUT IMPEDANCE

X3.1 The electrical circuit configuration and its equivalent circuit used for measuring input impedance are shown in Fig. X3.1. The attenuator is necessary to apply small voltages to the input of high gain systems. Many appropriate oscillators have built in attenuators. It is important that the outputs of such instruments be terminated with the proper load resistance in order for the attenuator to remain calibrated over its complete range. If a separate attenuator is used with an oscillator, and if the attenuator impedance does not match the oscillator output impedance, it is important that they be matched with a pad that presents the proper load to the oscillator and the proper source impedance to the attenuator. Fig. X3.1 illustrates the circuit of the pad. The required pad resistance values R_1 and R_2 are calculated from:

$$R_1 = \sqrt{R_{osc}(R_{osc} - R_S)} \quad and\ R_2 = R_{osc}R_S/R_1$$

where:

R_{osc} = the output impedance of the oscillator, and
R_S = the characteristic impedance of the attenuator.

Attenuators commonly require a 50-ohm source and a 50-ohm load to perform properly. Oscillators commonly have outputs of either 50 or 600 ohms. Do not substitute a potentiometer in place of a true attenuator. A separate attenuator also must be loaded with its characteristic resistance in order to operate as expected.

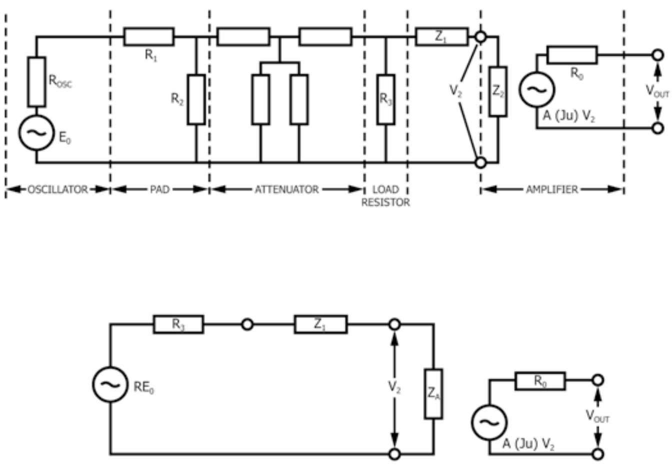

FIG. X3.1 Input Impedance Measurement Circuit Configuration and Equivalent Circuit

X3.2 Referring again to Fig. X3.1, measurements of the output voltage under two different conditions allows calculation of the input impedance using:

$$Z_A = \frac{V_{O2}\,(R + R_S) - V_{O1}\,R_S}{V_{O1} - V_{O2}} \pm \angle\ \theta = R_A \pm jX_A$$

where:

V_{O1} = the output voltage measured when Z_1 is zero,
V_{O2} = the output voltage when Z_1 = R is some value greater than zero subject only to the condition that the change in output voltage caused by the insertion of R is reasonably large so it is easy to measure,
R_S = the output impedance of the attenuator, and
θ = the phase angle between the voltage measured across R and that measured across Z_A when Z_1 = R.

Since most practical AE instruments have input resistance no larger than 50 000 ohms and input shunt capacitance no larger than 10 000 picofarads, it is possible to make reasonably accurate estimates of their magnitudes by finding that pure resistive value for Z_1 that will reduce the output voltage to ½ of the value it had when $Z_1 = 0$ for an input frequency at around 10 kHz. Then the resistive part of the input impedance is equal to the selected value. Similarly the value of capacitance substituted for Z_1 that reduces the output to ½ of the $Z_1 = 0$ value when the input frequency is above 500 kHz will be equal to the shunt capacitance component of the input impedance. If inductive components are used in the amplifier input the manufacturer should provide clear instructions and cautions about the use and response of their equipment. An exact match is not necessary since in the low frequency limit when $Z_1 = R$, the resistance can be estimated from:

$$R_A = R\left[V_{O2}/(V_{O1} - V_{O2})\right]$$

and in the high frequency limit when $Z_1 = ½\ fC$, the capacitive component can be estimated from:

$$C_A = C\left[V_{O1}/(V_{O2} - V_{O2})\right]$$

X4. NOISE SOURCES AND MEASUREMENT PROBLEMS

X4.1 *Types of Noise*—Noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. Noise may be erratic, intermittent, or statistically random. Noise is further defined as acoustic noise or electric noise to avoid ambiguity. This section is concerned with identifiable and controllable noise sources.

X4.2 *Acoustic Noise Sources:*

X4.2.1 Acoustic noise is detected by the sensor as a mechanical wave. This may be noise generated by reactive agents in contact with a specimen, loading fixture noise, or fluid noise. Fluid noise may be generated when orifice size and fluid flow velocity form an effective Helmholtz resonator. The signals generated by leaks may or may not be considered artifact noise, depending on the application of the acoustic emission technique or instrumentation.

X4.2.2 Thermal emission may be considered noise for some applications of AE examination. Thermal emission should become relevant when either the specimen or sensor is subjected to temperature changes. Thermal emission is often generated by material phase change, material geometry change (stick-slip AE), and the pyroelectric effect of some sensors. Many other sources of acoustic noise exist, but are not discussed here in the interest of brevity.

X4.3 *Electrical Noise Sources:*

X4.3.1 Electrical noise is noise coupled to the acoustic emission instrumentation by electrical conduction or radiation. The preponderance of electrical noise is synchronized to the power mains frequency. Electrical noise may contain the largest number of high-amplitude harmonics of any signal detected. Electrical noise may also be stable and continuous, or random in amplitude and repetition rate. Ground loops are often a problem at one work area, but may not be a problem at an adjacent work area. Radio transmitters may be another source of intermittent noise. Radio transmitters may include the traditional voice transmission units, or such sources as electrical motors, fluorescent lamps, and resistance welding.

X4.3.2 Noise may be introduced to the amplifier from noise impulses on the power mains through inadequately filtered power supplies. The noise is often intermittent and includes random impulse or burst signals of short duration and very fast rise time compared with acoustic emission signals. A series of several low pass, power main filters will often suppress this noise to an acceptable level.

X4.4 *Electronic Component Noise*—There are several sources of noise in electronic circuits. In practice, the noise figure of an amplifier is usually determined by the first, or input, stage of the amplifier. This is because noise introduced by other succeeding circuits of the instrumentation will undergo less amplification, and, thus, will be relatively unimportant in the instrumentation as long as the amplification of the first stage is moderate.

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STANDARD GUIDE FOR DETERMINING THE REPRODUCIBILITY OF ACOUSTIC EMISSION SENSOR RESPONSE

SE-976

(Identical with ASTM Specification E976-10.)

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SE-976

(Identical with ASTM Specification E 976-10)

1. Scope

1.1 This guide defines simple economical procedures for testing or comparing the performance of acoustic emission sensors. These procedures allow the user to check for degradation of a sensor or to select sets of sensors with nearly identical performances. The procedures are not capable of providing an absolute calibration of the sensor nor do they assure transferability of data sets between organizations.

1.2 *Units* — The values stated in SI units are to be regarded as standard. No other units of measurements are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 750 Practice for Characterizing Acoustic Emission Instrumentation

E 2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod

E 2374 Guide for Acoustic Emission System Performance Verification

3. Significance and Use

3.1 Acoustic emission data is affected by several characteristics of the instrumentation. The most obvious of these is the system sensitivity. Of all the parameters and components contributing to the sensitivity, the acoustic emission sensor is the one most subject to variation. This variation can be a result of damage or aging, or there can be variations between nominally identical sensors. To detect such variations, it is desirable to have a method for measuring the response of a sensor to an acoustic wave. Specific purposes for checking sensors include: *(1)* checking the stability of its response with time; *(2)* checking the sensor for possible damage after accident or abuse; *(3)* comparing a number of sensors for use in a multichannel system to ensure that their responses are adequately matched; and *(4)* checking the response after thermal cycling or exposure to a hostile environment. It is very important that the sensor characteristics be always measured with the same sensor cable length and impedance as well as the same preamplifier or equivalent. This guide presents several procedures for measuring sensor response. Some of these procedures require a minimum of special equipment.

3.2 It is not the intent of this guide to evaluate AE system performance. Refer to Practice E 750 for characterizing acoustic instrumentation and refer to Guide E 2374 for AE system performance verification.

3.3 The procedures given in this guide are designed to measure the response of an acoustic emission sensor to an arbitrary but repeatable acoustic wave. These procedures in *no* way constitute a calibration of the sensor. The absolute calibration of a sensor requires a complete knowledge of the characteristics of the acoustic wave exciting the sensor or a previously calibrated reference sensor. In either case, such a calibration is beyond the scope of this guide.

3.4 The fundamental requirement for comparing sensor responses is a source of repeatable acoustic waves. The characteristics of the wave do not need to be known as long as the wave can be reproduced at will. The sources and geometries given in this guide will produce primarily compressional waves. While the sensors will respond differently to different types of waves, changes in the response to one type of wave will imply changes in the responses to other types of waves.

3.5 These procedures all use a test block or rod. Such a device provides a convenient mounting surface for the sensor and when appropriately marked, can ensure that the source and the sensor are always positioned identically with respect to each other. The device or rod also provides mechanical loading of the sensor similar to that experienced in actual use. Care must be taken when using these devices to minimize resonances so that the characteristics of the sensor are not masked by these resonances.

3.6 These procedures allow comparison of responses only on the same test setup. No attempt should be made to compare responses on different test setups, whether in the same or separate laboratories.

4. Apparatus

4.1 The essential elements of the apparatus for these procedures are: *(1)* the acoustic emission sensor under test; *(2)* a block or rod; *(3)* a signal source; and *(4)* measuring and recording equipment.

4.1.1 Block diagrams of some of the possible experimental setups are shown in Fig. 1.

4.2 *Blocks* — The design of the block is not critical. However, the use of a "nonresonant" block is recommended for use with an ultrasonic transducer and is required when the transducer drive uses any form of coherent electrical signal.

4.2.1 *Conical "Nonresonant" Block* — The Beattie block, shown in Fig. 2, can be machined from a 10-cm diameter metal billet. The preferred materials are aluminum and low-alloy steel. After the bottom is faced and the taper cut, the block is clamped at a 10 deg angle and the top face is milled. The dimensions given will provide an approximate circle just over 2.5 cm in diameter for mounting the sensor. The acoustic excitation should be applied at the center of the bottom face. The conic geometry and lack of any parallel surfaces reduce the number of mechanical resonances that the block can support. A further reduction in possible resonances of the block can be achieved by roughly machining all surfaces except where the sensor and exciter are mounted and coating them with a layer of metal-filled epoxy.

4.2.2 *Gas-Jet Test Block* — Two gas-jet test blocks are shown in Fig. 3. The block shown in Fig. 3(a) is used for opposite surface comparisons, which produce primarily compressional waves. That shown in Fig. 3(b) is for same surface comparisons which produce primarily surface waves. The "nonresonant" block described in 4.2.1 can also be used with a gas jet in order to avoid exciting many resonant modes. The blocks in Fig. 3 have been used successfully but their design is not critical. However it is suggested that the relative positions of the sensor and the jet be retained.

4.2.3 *Acrylic Polymer Rod* — A polymethylmethacrylate rod is shown in Fig. 4. The sensor is mounted on the end of the rod and the acoustic excitation is applied by means of pencil lead break, a consistent distance from the sensor end of the rod. See Practice E 2075 for additional details on this technique.

4.3 *Signal Sources* — Three signal sources are recommended: an electrically driven ultrasonic transducer, a gas jet, and an impulsive source produced by breaking a pencil lead.

4.3.1 *Ultrasonic Transducer* — Repeatable acoustic waves can be produced by an ultrasonic transducer permanently bonded to a test block, or attached face-to-face to the AE sensor under test. The transducer should be heavily damped to provide a broad frequency response and have a center frequency in the 2.25 to 5.0-MHz range. The diameter of the active element should be at least 1.25 cm to provide measurable signal strength at the position of the sensor under test. The ultrasonic transducer should be checked for adequate response in the 50- to 200-kHz region before permanent bonding to the test block.

4.3.1.1 *White Noise Generator* — An ultrasonic transducer driven by a white noise generator produces an acoustic wave that lacks coherent wave trains of many wave lengths at one frequency. This lack of coherent wave trains greatly reduces the number and strength of the mechanical resonances excited in a structure. Therefore, an ultrasonic transducer driven by a white-noise generator can be used with a resonant block having parallel sides. However, the use of a "nonresonant" block such as that described in 4.2.1 is strongly recommended. The generator should have a white-noise spectrum covering at least the frequency range from 10 kHz to 2 MHz and be capable of an output level of 1 V rms.

4.3.1.2 *Sweep Generator* — The ultrasonic transducer can be driven by a sweep generator (or swept wave burst) in conjunction with a "nonresonant" block. Even with this block, some resonances will be produced that may partially mask the response of the sensor under test. The sweep generator should have a maximum frequency of at least 2 MHz and should be used with a digital oscilloscope or waveform based data acquisition system with frequency analysis (FFT) capabilities to analyze the resulting response of the sensor under test.

FIG. 1 BLOCK DIAGRAMS OF POSSIBLE EXPERIMENTAL SETUPS

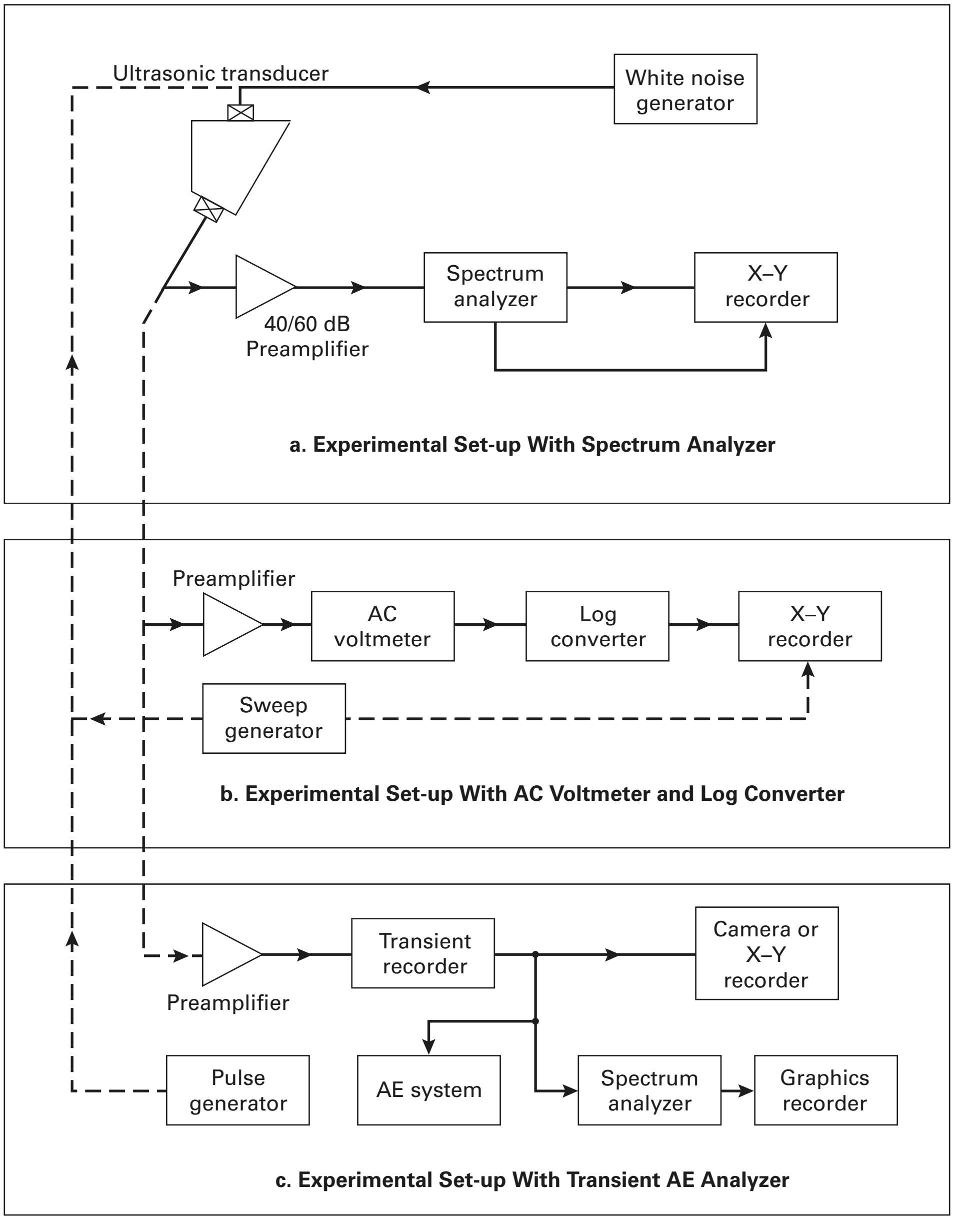
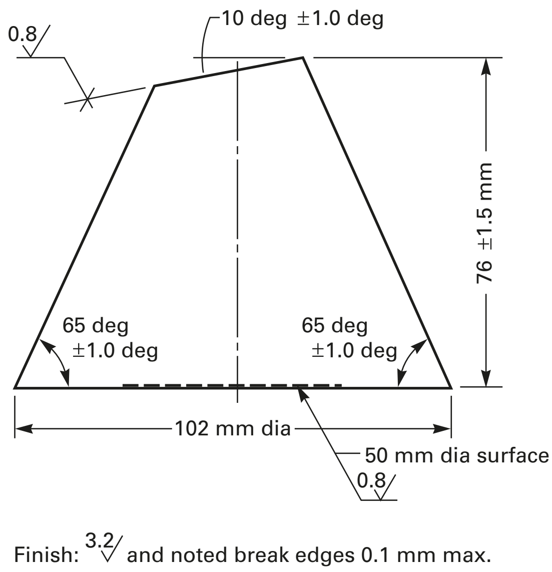


FIG. 2 THE BEATTIE BLOCK



4.3.1.3 *Pulse Generator* — The ultrasonic transducer may be excited by a pulse generator. The pulse width should be either slightly less than one-half the period of the center frequency of the transducer (≤0.22 µs for a 2.25 MHz transducer) or longer than the damping time of the sensor, block, and transducer (typically >10 ms). The pulse repetition rate should be low (<100 pulses/s) so that each acoustic wave train is damped out before the next one is excited.

4.3.1.4 The pulse generator should be used with a digital oscilloscope or waveform based data acquisition system (such as a waveform based AE system) or, in single-pulse mode, with the counter in an acoustic emission system.

4.3.2 *Gas Jet* — Suitable gases for this apparatus are extra dry air, helium, etc. A pressure between 150 and 200 kPa is recommended for helium or extra dry air. Once a pressure and a gas has been chosen, all further tests with the apparatus should use that gas and pressure. The gas jet should be permanently attached to the test block [see Fig. 3(a) and 3(b)].

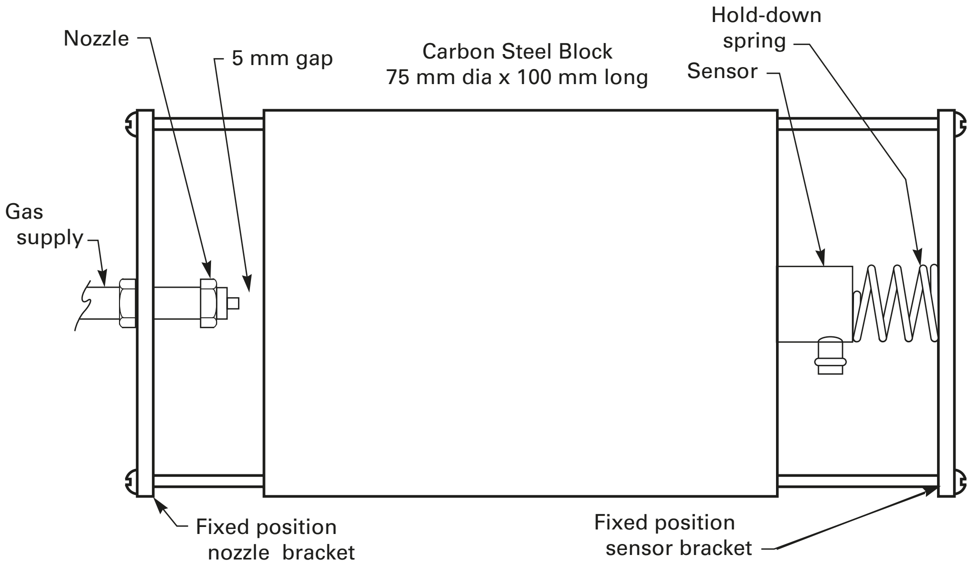
4.3.3 *Pencil Lead Break* — A repeatable acoustic wave can be generated by carefully breaking a pencil lead against the test block or rod. When the lead breaks, there is a sudden release of the stress on the surface of the block where the lead is touching. This stress release generates an acoustic wave. The Hsu pencil source uses a mechanical pencil with a 0.3-mm diameter lead (0.5-mm lead is also acceptable but produces a larger signal). The Nielsen shoe, shown in Fig. 5, can aid in breaking the lead consistently. Care should be taken to always break the same length of the same type of lead (lengths between 2 and 3 mm are preferred). The lead should always be broken at the same spot on the block or rod with the same angle and orientation of the pencil. Spacing between the lead break and sensor should be at least 10 cm. With distances shorter than that, it is harder to get consistent results. The most desirable permanent record of a pencil lead break is the wave form captured by a waveform based data acquisition system (such as an AE waveform based instrument) with frequency analysis (FFT) capabilities.

4.4 *Measuring and Recording Equipment* — The output of the sensor under test must be amplified before it can be measured. After the measurement, the results should be stored in a form that allows an easy comparison, either with another sensor or with the same sensor at a different time.

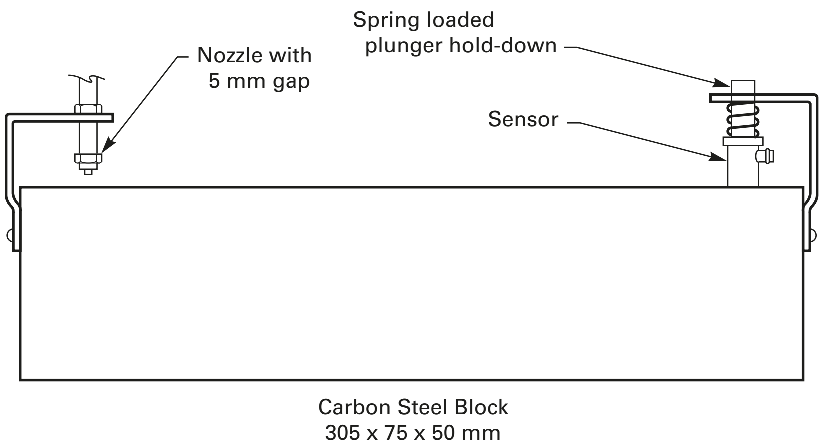
4.4.1 *Preamplifier* — The preamplifier, together with the sensor to preamp coaxial cable, provides an electrical load for the sensor, amplifies the output, and filters out unwanted frequencies. The electrical load on the sensor can distort the low-frequency response of a sensor with low inherent capacitance. To prevent this from occurring, it is recommended that short sensor cables (<2 m) be used and the resistive component of the preamplifier input impedance be 20 kΩ or greater. The preamplifier gain should be fixed. Either 40 to 60-dB gains are suitable for most sensors. The bandpass of the preamplifier should be at least 20 to 1200 kHz. It is recommended that one preamplifier be set aside to be used exclusively in the test setup. However, it may be appropriate at times to test a sensor with the preamplifier assigned to it in an experiment.

4.4.2 *Waveform Based Instruments and Storage Oscilloscopes* — The waveform generated by a sensor in response to a single pulse or a pencil lead break can be

FIG. 3 GAS-JET TEST BLOCKS

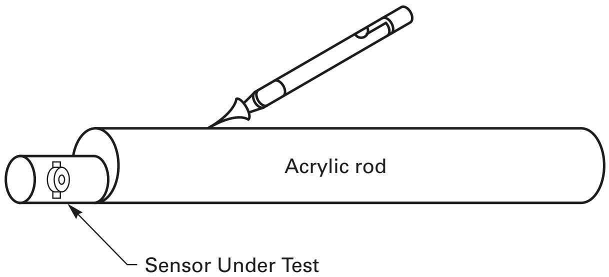


(a) Opposite Surface Comparison Test



(b) Same Surface Comparison Test

FIG. 4 ACRYLIC POLYMER ROD



measured and stored by a transient recorder, digital oscilloscope, or a waveform-based acoustic emission system. This waveform can be recorded on computer media, displayed on a computer screen or printed out on a printer. Digitization rates should be at least 10 samples per highest frequency period in the waveform. Lower rates might result in distortion or loss of amplitude accuracy of the wave shape. When comparing waveforms, emphasis should be placed on the initial few cycles and on the large amplitude features. Small variations late in the waveform are often produced by slight changes in the coupling or position of the sensor under test. The waveform can also be converted into the frequency domain by means of a fast fourier transform (FFT) for amplitude versus frequency response analysis.

4.4.3 *Spectrum Analyzers* — Spectrum analyzers can be used with acoustic signals generated by ultrasonic transducers that are driven by either white-noise generators or tracking-sweep generators, by gas-jet sources or by acoustic signals, produced by any source, that are captured on a transient recorder and replayed into the spectrum analyzer. A suitable spectrum analyzer should be capable of displaying a spectrum covering the frequency range from 20 kHz to 1.2 MHz. The amplitude should be displayed on a logarithmic scale covering a range from at least 50 dB in order to display the entire dynamic range of the sensor. The spectrum can be recorded photographically from an oscilloscope. However, the most useful output is an XY graph showing the sensor amplitude response or power versus frequency as shown in Fig. 6.

4.4.4 *Acoustic Emission System* — A sensor can be characterized by using an acoustic emission system and an impulsive source such as a pencil lead break, an ultrasonic (or AE) transducer driven by a pulse generator, or the impulsive source that is built into many AE systems with automated pulsing capabilities. One or more of several significant AE signal features (such as amplitude, counts or energy) can be used to characterize the sensor response. The acoustic emission features from each signal pulse should be measured for multiple pulses (at least three). Data recorded should be the individual AE feature values (for repeatability determination) and average value of the readings (for sensitivity determination). In addition, the system gain, preamplifier gain, filtering, and any other significant settings of acoustic emission system should be recorded.

4.4.5 *Voltmeters* — An a-c voltmeter can be used to measure sensor outputs produced by signals generated by an ultrasonic transducer driven by a sweep generator. The response of the voltmeter should be flat over the frequency range from 10 kHz to 2 MHz. It is desirable that the voltmeter either have a logarithmic output or be capable of driving a logarithmic converter. The output of the voltmeter or converter is recorded on an XY recorder as a function of frequency.

4.4.5.1 The limited dynamic range of an rms voltmeter makes it less desirable than an a-c averaging voltmeter when used with a sweep generator. However, a rough estimate of a sensor performance can be obtained by using an rms or a-c voltmeter to measure the output of a sensor driven by a wide band source such as a white-noise generator or a gas jet.

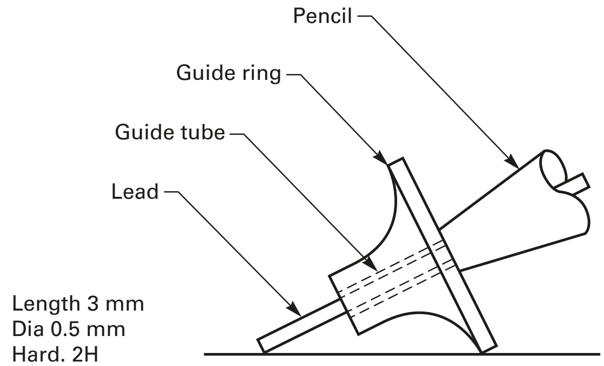
5. Procedure

5.1 Place the sensors under test on the test block or rod in as near to identical positions as possible. Use identical forces to hold the sensor and block (or rod) together. A low-viscosity couplant is desirable to ensure reproducible and minimum couplant thicknesses. For all setups, take several measurements before the final data is recorded to ensure reproducibility. During the initial measurements, display the preamplifier output on an oscilloscope or waveform based instrument to see that the signals are not being clipped by overdriving the preamplifier. Establish written procedures and follow them to ensure reproducibility over long periods of time.

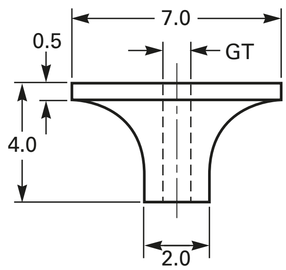
6. Interpretation of Results

6.1 Short-term reproducibility of results, covering such actions as removing and remounting the sensor, should be better than 3 dB if the test is conducted under normal working conditions. Long-term reproducibility of the test system should be checked periodically by the use of a reference sensor that is not exposed to the risk of environmental damage. Variations of sensor response greater than 4 dB indicates damage or degradation, and the cause of the discrepancy should be further investigated. While there are no set criteria for acceptable limits on sensor degradation, a sensor whose sensitivity had fallen by more than 6 dB would generally be considered unfit for further service in acoustic emission measurements.

FIG. 5 GUIDE RING FOR IMPULSIVE SOURCE



(a) Nielsen Shoe on Hsu Pencil Source



Diameter	GT (±0.05 mm)
0.3 mm	0.84 mm
0.5 mm	0.92 mm

Guide ring
Teflon
Dimensions given in mm
Tolerances ±0.1 mm
(unless otherwise noted)

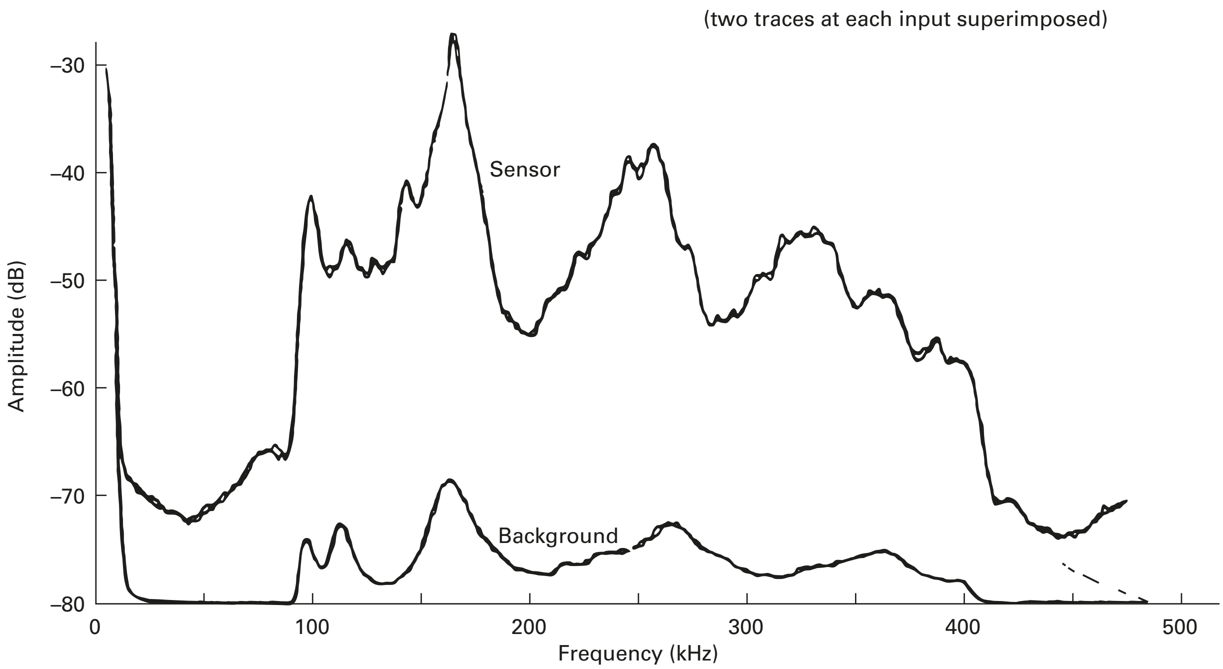
(b) Nielsen Shoe

FIG. 6 EXAMPLE OF AN X-Y RECORDER PLOT FROM A SPECTRUM ANALYZER (150 kHz RESONANT SENSOR)

Gas: extra dry air, 200 KPa
Nozzle: 0.25 mm dia diffused
Block: 305 mm x 75 mm x 50 mm carbon steel
Sensor and jet on same surface (50 x 305 mm), separation: 260 mm

AE instrumentation: Preamp: +40 dB gain
Amp: +21 dB gain
Filter: 100–400 kHz, bandpass

Spectrum analyzer: H.P. 8552B / 8553B
Center frequency: 250 kHz, bandwidth: 3 kHz
Scan/div: 50 kHz, Scan time: 2S/div
Input atten: 0 dB, log ref: 0 dB, 10 dB/division
Video filter: 10 Hz



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STANDARD PRACTICE FOR ACOUSTIC EMISSION EXAMINATION OF FIBERGLASS REINFORCED PLASTIC RESIN (FRP) TANKS/VESSELS

SE-1067/SE-1067M

(Identical with ASTM Specification E1067/E1067M-11.)

Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

1. Scope

1.1 This practice covers acoustic emission (AE) examination or monitoring of fiberglass-reinforced plastic (FRP) tanks-vessels (equipment) under pressure or vacuum to determine structural integrity.

1.2 This practice is limited to tanks-vessels designed to operate at an internal pressure no greater than 1.73 MPa absolute [250 psia] above the static pressure due to the internal contents. It is also applicable for tanks-vessels designed for vacuum service with differential pressure levels between 0 and 0.10 MPa [0 and 14.5 psi].

1.3 This practice is limited to tanks-vessels with glass contents greater than 15 % by weight.

1.4 This practice applies to examinations of new and in-service equipment.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (For more specific safety precautionary information see 8.1.)

2. Referenced Documents

2.1 *ASTM Standards:*

D883 Terminology Relating to Plastics

D5436 Specification for Cast Poly(Methyl Methacrylate) Plastic Rods, Tubes, and Shapes

E543 Specification for Agencies Performing Nondestructive Testing

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E1316 Terminology for Nondestructive Examinations

E2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod

E2374 Guide for Acoustic Emission System Performance Verification

2.2 *ANSI/ASNT Standards:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)

3. Terminology

3.1 Complete definitions of terms related to plastics and acoustic emission will be found in Terminology D883 and E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *FRP*—fiberglass reinforced plastic, a glass-fiber polymer composite with certain mechanical properties superior to those of the base resin.

3.2.2 *operating pressure*—the pressure at the top of a vessel at which it normally operates. It shall not exceed the design pressure and it is usually kept at a suitable level below the setting of the pressure-relieving devices to prevent their frequent opening.

3.2.3 *pressure, design*—the pressure used in design to determine the required minimum thicknesses and minimum mechanical properties.

3.2.4 *processor*—a circuit that analyzes AE waveforms. (See Section 7 and A1.8.)

3.2.5 *summing amplifier (summer, mixer)*—an operational amplifier that produces an output signal equal to a weighted sum of the input signals.

3.2.6 *zone*—the area surrounding a sensor from which AE can be detected by that sensor.

4. Summary of Practice

4.1 This practice consists of subjecting equipment to increasing pressure or vacuum while monitoring with sensors that are sensitive to acoustic emission (transient stress waves) caused by growing flaws. The instrumentation and techniques for sensing and analyzing AE data are described.

4.2 This practice provides guidelines to determine the location and severity of structural flaws in FRP equipment.

4.3 This practice provides guidelines for AE examination of FRP equipment within the pressure range stated in 1.2. Maximum test pressure (or vacuum) for an FRP vessel will be determined upon agreement among user, manufacturer, or test agency, or a combination thereof. Pressure vessels will normally be tested to 1.1 × operating pressure. Atmospheric storage vessels and vacuum vessels will normally be tested under maximum operating conditions. Vessels will normally be tested at ambient temperature. In the case of elevated operating temperature the test may be performed either at operating or ambient temperature.

5. Significance and Use

5.1 The AE examination method detects damage in FRP equipment. The damage mechanisms that are detected in FRP are as follows: resin cracking, fiber debonding, fiber pullout, fiber breakage, delamination, and bond failure in assembled joints (for example, nozzles, manways, etc.). Flaws in unstressed areas and flaws that are structurally insignificant will not generate AE.

5.2 This practice is convenient for on-line use under operating stress to determine structural integrity of in-service equipment usually with minimal process disruption.

5.3 Indications located with AE should be examined by other techniques; for example, visual, ultrasound, dye penetrant, etc., and may be repaired and tested as appropriate. Repair procedure recommendations are outside the scope of this practice.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice:

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with 9.2 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 13 unless otherwise specified. Since acceptance criteria are not specified in this practice, they shall be specified in the contractual agreement.

7. Instrumentation

7.1 The AE instrumentation consists of sensors, signal processors, and recording equipment. Additional information on AE instrumentation can be found in Practice E750.

7.2 Instrumentation shall be capable of recording AE hits, signal strength and hit duration and have sufficient channels to localize AE sources in real time. It may incorporate (as an option) peak-amplitude detection for each input channel or for groups of channels. Hit detection is required for each channel. An AE hit amplitude measurement is recommended for sensitivity verification (see Annex A2). Amplitude distributions are recommended for flaw characterization. It is preferred that AE instrumentation acquire and record duration hit and amplitude information on a per channel basis. The AE instrumentation is further described in Annex A1.

7.3 Capability for measuring parameters such as time and pressure shall be provided. The pressure-vacuum in the vessel should be continuously monitored to an accuracy of ±2 % of the maximum test value.

7.4 *Lockouts and Guard Sensors*—These techniques shall not be used.

7.5 *Instrument Displays*—- The instrumentation shall be capable of providing the following real time displays:

7.5.1 *Bar Chart by Channel of Cumulative Signal Strength*—Enables the inspector to identify which channel is recording the most data.

7.5.2 *Amplitude per Hit Versus Time*—Provides the inspector with early warning of an impending failure.

7.5.3 *Duration per Hit Versus Time*—Useful for identifying rubbing or sliding.

7.5.4 *Log Duration (or Counts) per Hit Versus Amplitude per Hit*—Helps the inspector determine the presence of false emission signals

7.5.5 *Cumulative Signal Strength per Channel Versus Time*—Useful for identifying certain types of instrument malfunctions.

7.6 *Cumulative Amplitude Distribution,* or a tabular listing by channel number of total hits equal to and greater than defined amplitude values. Tabular amplitude values shall be in increments of not greater than 5 dB and shall be for at least a 35 dB range beginning at the threshold. These displays are used to provide warning of significant fiber breakage of the type that can lead to sudden structural failure. The displays also provide information about the micromechanisms giving rise to the emission and warn of potential instrument malfunction.

8. Examination Preparations

8.1 *Safety*—All plant safety requirements unique to the examination location shall be met.

8.1.1 Protective clothing and equipment that is normally required in the area in which the examination is being conducted shall be worn.

8.1.2 A fire permit may be needed to use the electronic instrumentation.

8.1.3 Precautions shall be taken to protect against the consequences of catastrophic failure when pressure testing, for example, flying debris and impact of escaping liquid. Pressurizing under pneumatic conditions is not recommended except when normal service loads include either a superposed gas pressure or gas pressure only. Care shall be taken to avoid overstressing the lower section of the vessel when liquid test loads are used to simulate operating gas pressures.

8.1.4 Special safety precautions shall be taken when pneumatic testing is required; for example, safety valves, etc.

8.2 *Vessel Conditioning*—The operating conditions for vessels that have been stressed previously shall be reduced prior to examining in accordance with the schedule shown in Table 1. The maximum operating pressure or load in the vessel during the past year must be known in order to conduct the AE examination properly.

8.3 *Vessel Stressing*—Arrangements should be made to stress the vessel to the operating pressure-load where possible. The stress rate shall be sufficient to expedite the examination with minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure-load at designated check points.

8.3.1 *Atmospheric Tanks*—Process liquid is the preferred fill medium for atmospheric tanks. If water must replace the process liquid, the designer and user shall be in agreement on the procedure to achieve acceptable stress levels.

TABLE 1 Requirements for Reduced Operating Pressure-Load Immediately Prior to Examining

% of Operating Pressure or Load, or Both	Time at Reduced Pressure or Load, or Both
10 or less	12 h
20	18 h
30	30 h
40	2 days
50	4 days
60	7 days

8.3.2 *Vacuum-Tank Stressing*—A controllable vacuum-pump system is required for vacuum tanks.

8.3.3 *Pressure-Vessel Stressing*—Water is the preferred medium for pressure tanks. Safe means for hydraulically increasing the pressure under controlled conditions shall be provided.

8.4 *Tank Support*—The tank shall be examined in its operating position and supported in a manner consistent with good installation practice. Flat-bottomed tanks examined in other than the intended location shall be mounted on a pad (for example, rubber on a concrete base or equivalent) to reduce structure-borne noise between the tank and base.

8.5 *Environmental*—The normal minimum acceptable vessel wall temperature is 4°C [40°F].

8.6 *Noise Reduction*—Noise sources in the examination frequency and amplitude range, such as rain, spargers, and foreign objects contacting the tank, must be minimized since they mask the AE signals emanating from the structure. The inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, that is, below the liquid level. Liquid falling, swirling, or splashing can invalidate data obtained during the filling phase.

8.7 *Power Supply*—A stable grounded power supply, meeting the specification of the instrumentation, is required at the examination site.

8.8 *Instrumentation Settings*—Settings will be determined as described in Annex A2.

9. Sensors

9.1 *Sensor Mounting*—Refer to Practice E650 for additional information on sensor mounting. Location and spacing of the sensors are discussed in 9.3. Sensors shall be placed in designated locations with a couplant between the sensor and examination article. One recommended couplant is silicone-stopcock grease. Care must be exercised to assure that adequate couplant is applied. Sensors shall be held in place utilizing methods of attachment which do not create extraneous signals. Methods of attachment using crossed strips of pressure-sensitive tape or suitable adhesive systems, may be considered. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method should provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or pulling the sensor away from the examination article causing loss of coupling.

9.2 *Surface Contact*—Reliable coupling between the sensor and tank surface shall be assured and the surface of the vessel in contact with the sensor shall be clean and free of particulate matter. Sensors should be mounted directly on the tank surface unless integral waveguides shown by test to be satisfactory are used. Preparation of the contact surface shall be compatible with both sensor and structure modification requirements. Possible causes of signal loss are coatings such as paint and encapsulants, surface curvature, and surface roughness at the contact area.

9.3 *Locations and Spacings*—Locations on the vessel shell are determined by the need to detect structural flaws at critical sections; for example, high-stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Spacings are governed by the attenuation of the FRP material.

9.3.1 *Attenuation Characterization*—Typical signal propagation losses shall be determined in accordance with the following procedure. This procedure provides a relative measure of the attenuation, but may not be representative of genuine AE activity. It should be noted that the peak amplitude from a mechanical pencil lead break may vary with surface hardness, resin condition, and cure. The attenuation characterization should be made above the liquid line.

9.3.1.1 Select a representative region of the vessel away from manways, nozzles, etc. Mount an AE sensor and locate points at distances of 150 mm [6 in.] and 300 mm [12 in.] from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points on the surface of the vessel at 150 mm [6 in.] and 300 mm [12 in.] along a line inclined 45° to the direction of the original points. At each of the four points, break 0.3 mm 2H leads and record peak amplitude. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. The data shall be retained as part of the original experimental record.

9.3.2 *Sensor Spacings*—The recommended sensor spacing on the vessel shall not be greater than 3 × the distance at which detected signals from the attenuation characterization equal the threshold setting.

9.3.3 *Sensor Location*—Sensor location guidelines for the following tank types are given in the Annex. Other tank types require an agreement among the owner, manufacturer, or examination agency, or combinations thereof.

9.3.3.1 *Case I: Atmospheric Vertical Tank*—flat bottom, flanged and dished head, typical nozzle and manway configuration, cylindrical shell fabricated in two sections with secondary bond-butt joint, dip pipe.

9.3.3.2 *Case II: Atmospheric Vertical Tank*—flat bottom, 2:1 elliptical head, typical nozzle and manway configuration, agitator with baffles, cylindrical shell fabricated in one section.

9.3.3.3 *Case III: Atmospheric-Pressure Vertical Tank*—flanged and dished heads top and bottom, typical nozzle and manway configuration, packing support, legs attached to cylindrical shell, cylindrical shell fabricated in one section.

9.3.3.4 *Case IV: Atmospheric-Pressure Vertical Tank*—cone bottom, 2:1 elliptical head, typical nozzle and manway configuration, cylindrical shell fabricated in two sections, body flange, dip pipe, support ring.

9.3.3.5 *Case V: Atmospheric-Vacuum Vertical Tank*—flanged and dished heads top and bottom, typical nozzle and manway configuration, packing support, stiffening ribs, support ring, cylindrical shell fabricated in two sections with secondary bond-butt joint.

9.3.3.6 *Case VI: Atmospheric-Pressure Horizontal Tank*—flanged and dished heads, typical nozzle and manway configuration, cylindrical shell fabricated in two sections with secondary bond-butt joint, saddle supports.

10. Instrumentation System Performance Check

10.1 *Sensor Coupling and Circuit Continuity Verification*—Verification shall be performed following sensor mounting and system setup. The response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source should be recorded and evaluated prior to the examination (see Guide E2374).

10.1.1 The peak amplitude of the simulated event at a specific distance from each sensor should not vary more than 6 dB from the average of all the sensors. Any sensor-preamplifier combination failing this check should be investigated and replaced or repaired as necessary.

10.2 *Background Noise Check*—A background noise check is recommended to identify and determine the level of spurious signals. This is done following the completion of the verification described in 10.1 and prior to stressing the vessel. A recommended time period is 20 minutes.

11. Examination Procedure

11.1 *General Guidelines*—The tank-vessel is subjected to programmed increasing pressure-load levels to a predetermined maximum while being monitored by sensors that detect acoustic emission (stress waves) caused by growing structural flaws.

11.1.1 Fill and pressurization rates shall be controlled so as not to exceed a strain rate of 0.005 %/min based on calculated values or actual strain gage measurements of principal strains. Normally, the desired pressure will be attained with a liquid (see 8.1.3 and 8.1.4). Pressurization with a gas (air, N_2 etc.) is not recommended. A suitable manometer or other type gage shall be used to monitor pressure.

11.1.2 Vacuum should be attained with a suitable vacuum source. A quick release valve shall be provided to handle any imminent catastrophic failure condition.

11.1.3 Background noise shall be minimized and identified (see also 8.6). Excessive background noise is cause for suspension of the pressurization. In the analysis of examination results, background noise should be properly discounted. Sources of background noise include the following: liquid splashing into a tank, a fill rate that is too high, pumps, motors, agitators and other mechanical devices, electromagnetic interference, and environmental factors, such as rain, wind, etc.

11.2 *Loading*—Atmospheric tanks that operate with liquid head and pressures of 0.2 MPa [30 psia] or less, and vacuum vessels that operate at pressures below atmospheric, shall be loaded in a series of steps. Recommended load procedures are shown in Fig. 1 and Fig. 2. The algorithm flow chart for this class of tanks is given in Fig. 3.

11.2.1 For tanks that have been stressed previously, the examination can begin with the liquid level as high as 60 % of the operating or maximum test level (see 8.2). Fig. 1 should be modified for vessels that are partially full at the beginning of an examination. The background noise baseline determination is important for this class of examination and should be provided

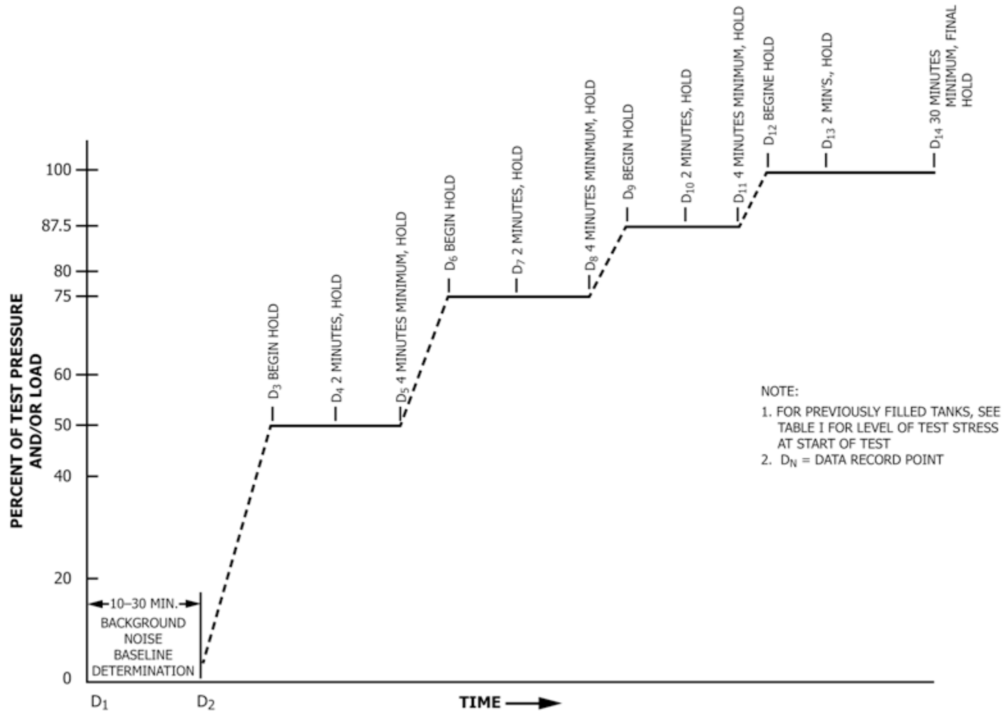


FIG. 1 Atmospheric Tank Examination, Stressing Sequence

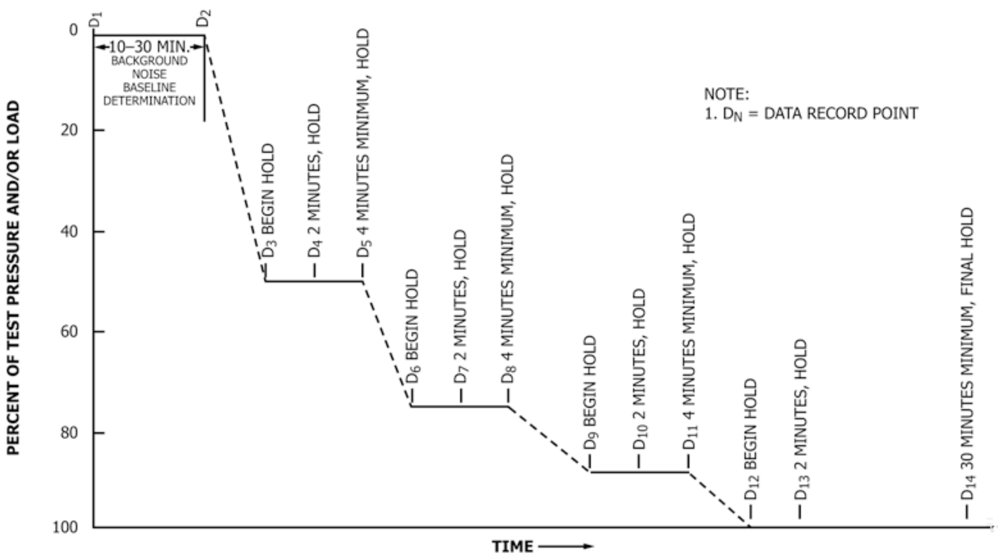


FIG. 2 Vacuum Tank Examination, Stressing Sequence

for. Many vessels operate with liquid contents and partial vacuum; however, vacuum vessels are normally examined empty.

11.2.2 Pressure vessels that operate with superimposed pressures greater than 0.2 MPa [30 psia] shall be loaded as shown in Fig. 4. The algorithm flow chart for this class of tanks is given in Fig. 5.

11.2.3 The initial hold period is used to determine a baseline of the background noise. This data provides an estimate of the total background noise contribution during the examination. Background noise shall be discounted in the final data analysis.

11.2.4 Intermittent load holds shall be for 4 min. As shown in Fig. 4, pressure vessels shall be loaded in steps up to 30 % of the maximum test pressure. Thereafter, the pressure shall be

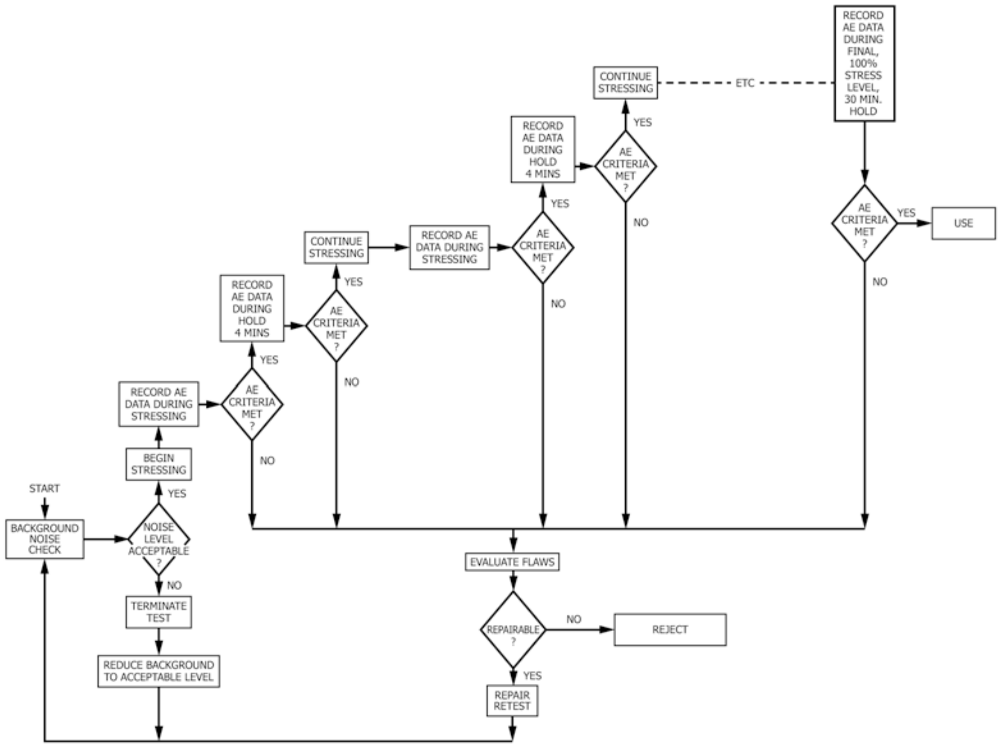


FIG. 3 AE Examination Algorithm—Flow Chart Atmospheric-Vacuum Tanks (See Fig. 1 **and** Fig. 2**.)**

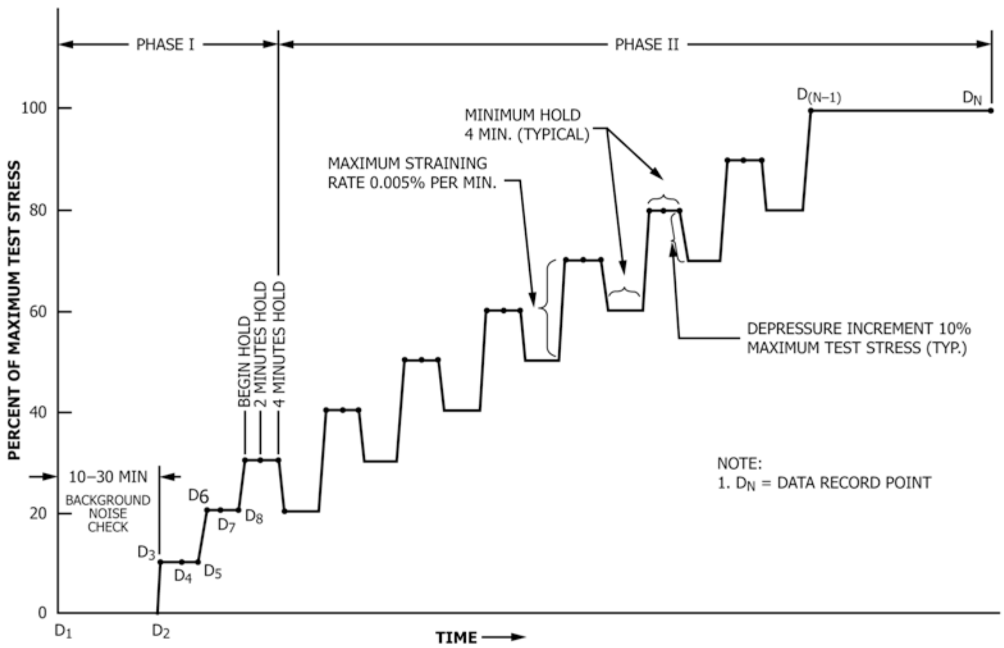


FIG. 4 Pressure Tank Examination, Stressing Sequence

decreased by 10 % of the maximum test pressure before proceeding to the next hold level. Following a decrease in pressure, the load shall be held for 4 min before reloading.

11.2.5 For all vessels, the final load hold shall be for 30 min. The vessel should be monitored continuously during this period.

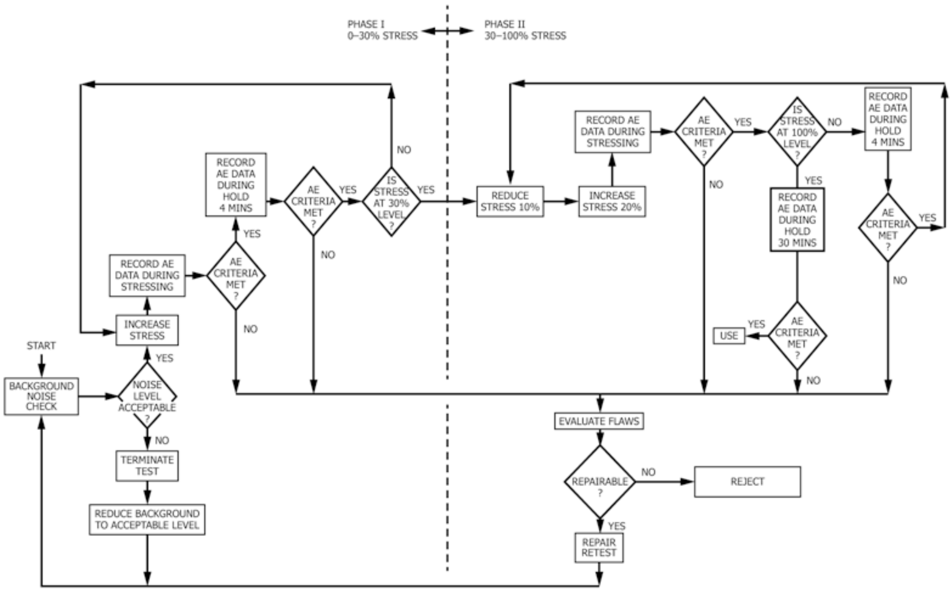


FIG. 5 AE Examination Algorithm—Flow Chart Pressure Tanks (See Fig. 4.)

11.3 *Felicity Ratio Determination*—The Felicity ratio is not measured during the first loading of atmospheric tanks and vacuum vessels. The Felicity ratio is obtained directly from the ratio of the stress at the emission source at onset of significant emission and the maximum prior stress at the same point.

11.3.1 The Felicity ratio is measured from the unload-reload cycles during the first loading of pressure vessels. For subsequent loadings, the Felicity ratio is obtained directly from the ratio of the stress at the emission source at onset of emission and the previous maximum stress at the same point. A secondary Felicity ratio is determined from the unload-reload cycles.

11.4 *Data Recording*—Prior to an examination, the signal propagation loss (attenuation) data, that is, amplitude as a function of distance from the signal source, shall be recorded in accordance with the procedure detailed in 9.3.

11.4.1 The number of hits from all channels whose amplitude exceeds the threshold setting shall be recorded. Channels that are active during load holds should be noted.

12. Interpretation of Results

12.1 *Examination Termination*—The real-time instrument displays shall be continuously monitored during the test. If any of these displays indicate approaching failure, the vessel shall be unloaded and the test terminated. If the inspector judges background noise to be excessive during the test, the test shall be terminated. "Excessive" background noise is a matter of judgment based on experience.

12.2 *Significance of Data:*

12.2.1 Evaluation based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold. Continuing emission during hold periods is a condition on which acceptance criteria may be based.

12.2.2 Evaluation based on Felicity ratio is important for in-service vessels. The Felicity ratio provides a measure of the severity of previously induced damage. The onset of "significant" emission for determining measurement of the Felicity ratio is a matter of experience. The following are offered as guidelines to determine if emission is significant:

12.2.2.1 More than five bursts of emission during a 10 % increase in load.

12.2.2.2 More than $N_d/2$ duration during a 10 % increase in load, where N_d is the total duration value defined in Annex A2.

12.2.2.3 Emission continues at a load hold. For purposes of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

12.2.2.4 Felicity ratio is a condition on which acceptance criteria may be based.

12.2.3 Evaluation based on high-amplitude events is important for new vessels. These events are often associated with fiber breakage and are indicative of major structural damage. This condition is less likely to govern for in-service and previously loaded vessels where emissions during a load hold and Felicity ratio are more important. High-amplitude events is a condition on which acceptance criteria may be based.

12.2.4 Evaluation based on total duration is valuable for atmospheric and vacuum tanks. Pressure vessels, particularly on first loading, tend to be noisy and therefore evaluation for pressure vessels is based on reloading only. Total duration is a condition on which acceptance criteria may be based.

12.2.5 Indications located with AE should be examined by other techniques; for example, visual, ultrasonics, dye penetrant, etc.

13. Report

13.1 The report shall include the following:

13.1.1 Complete identification of equipment, including material type, source, method of fabrication, manufacturer's name and code number, date and pressure-load of previous tests, and previous history.

13.1.2 Equipment sketch or manufacturer's drawing with dimensions of equipment and sensor location.

13.1.3 Test liquid employed.

13.1.4 Test liquid temperature.

13.1.5 *Test Sequence*—filling rate, hold times, and hold levels.

13.1.6 Comparison of examination data with specified acceptance criteria.

13.1.7 Show on sketch or manufacturer's drawing the location of any suspect areas found that require further evaluation.

13.1.8 Any unusual effects or observations during or prior to the examination.

13.1.9 Dates of examination.

13.1.10 Name(s) of examiner(s).

13.1.11 *Instrumentation Description*—complete description of AE instrumentation including manufacturer's name, model number, sensor type, system gain, serial numbers or equivalent, software title and version number, etc.

13.1.12 *Permanent Record of AE Data,* for example, AE hits versus time for zones of interest, total duration above the threshold setting versus time, emissions during load holds, and signal propagation loss.

14. Keywords

14.1 felicity effect; felicity ratio; fiber debonding; fiber pullout; resin cracking; source characterization; source location

ANNEXES

(Mandatory Information)

A1. INSTRUMENTATION PERFORMANCE REQUIREMENTS

A1.1 *AE Sensors:*

A1.1.1 *General*—AE sensors shall be temperature-stable over the range of use which may be 4° to 93°C [40° to 200° F], and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice or differential (anticoincident) element design, or both. Sensors shall have omnidirectional response in the plane of contact with variations not exceeding 4 dB from the peak response.

A1.1.2 *Sensors*—Sensors shall have a resonant response between 100 and 200 kHz. Minimum sensitivity shall be −80 dB referred to 1 volt per microbar, determined by face-to-face ultrasonic test.

NOTE A1.1—This method measures approximate sensitivity of the sensor. AE sensors used in the same examination should not vary in peak sensitivity more than 3 dB from the average.

A1.2 *Signal Cable*—The signal cable from sensor to preamp shall not exceed a length that will cause more than 3 dB of signal loss (typically 2 m [6 ft]) and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the sensor housing, or a line-driving (matched impedance) sensor is used.

A1.3 *Couplant*—Commercially available couplants for ultrasonic flaw detection may be used. Frangible wax or quick-setting adhesives may be used, provided couplant sensitivity is not significantly lower than with fluid couplants. Couplant selection should be made to minimize change in coupling sensitivity during an examination. Consideration should be given to testing time and the surface temperature of the vessel.

A1.4 *Preamplifier*—The preamplifier should be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamplifier is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. The preamplifier bandpass shall be consistent with the frequency range of the sensor and shall not attenuate the resonant frequency of the sensor.

A1.5 *Filters*—Filters shall be of the band pass type, and shall provide a minimum of 24 dB per octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamplifier, or processor to limit frequency response. Filters or integral design characteristics, or both, shall ensure that the principal processing frequency is between 100 and 200 kHz.

A1.6 *Power-Signal Cable*—The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB/30 m [100 ft] of cable length at 150 kHz. The recommended maximum cable length to avoid excessive signal attenuation is 150 m [500 ft]. Digital or radio transmission of signals is allowed consistent with practice in transmitting those signal forms.

A1.7 *Main Amplifier*—The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range of 25 to 200 kHz, and temperature range of 4 to 52°C [40 to 125°F]. The main amplifier shall have adjustable gain, or an adjustable threshold for hit detection and counting.

A1.8 *Main Processor:*

A1.8.1 *General*—The main processor(s) shall be capable of processing hits, peak amplitude, signal strength, and duration on each channel.

A1.8.2 *Peak-Amplitude Detection*—Comparative calibration must be established in accordance with the requirements of Annex A2. Usable dynamic range shall be a minimum of 60 dB with 2 dB resolution. Not more than 2-dB variation in peak-detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or dB, but must be referenced to a fixed gain output of the system (sensor or preamplifier).

A1.8.3 *Signal Outputs and Recording*—The processor as a minimum shall provide outputs for permanent recording of duration, amplitude, signal strength, and hits above the threshold setting by channel (zone location) and hits. A sample system schematic is shown in Fig. A1.1.

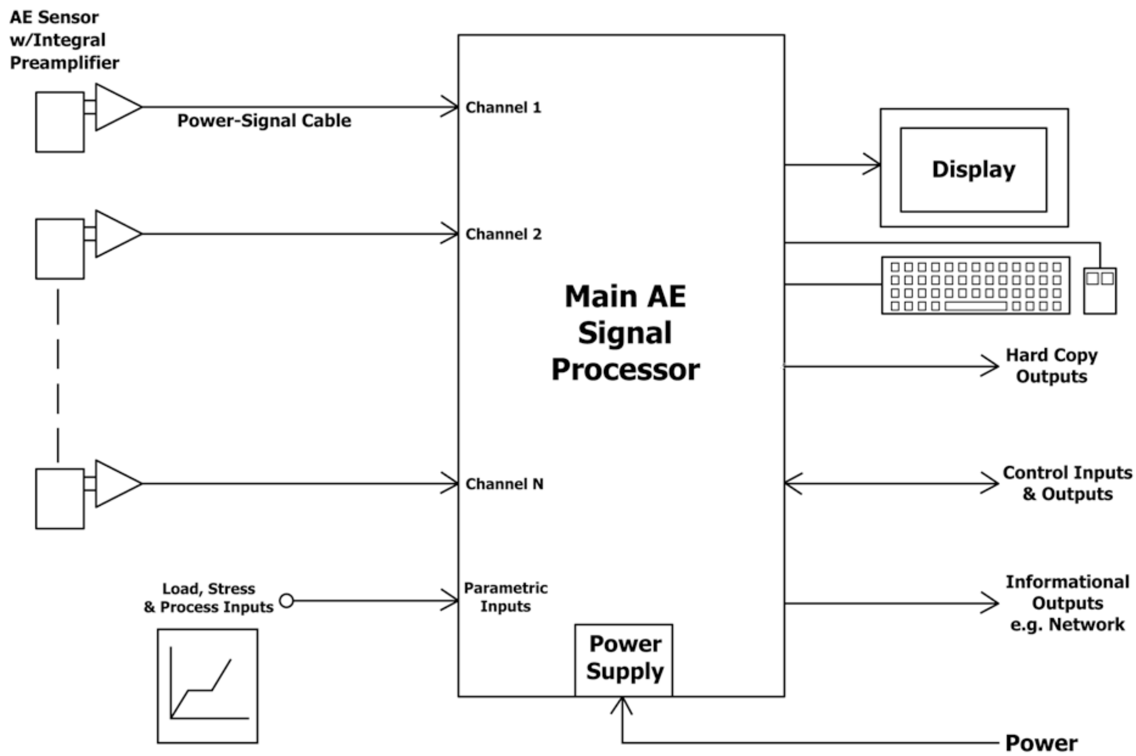


FIG. A1.1 Sample Schematic of AE Instrumentation for Vessel Testing

A2. INSTRUMENT SETTINGS

A2.1 *General*—The performance and threshold definitions vary for different types of acoustic emission instrumentation. Parameters such as signal strength and amplitude may vary from manufacturer to manufacturer and from model to model by the same manufacturer. This annex describes techniques for generating common baseline levels for the different types of instrumentation. Through the use of these procedures the test sensitivity can be effectively the same regardless of instrumentation manufacturer or equipment nomenclature.

A2.1.1 The procedures described in A2.2 and A2.3 should be performed at a temperature of 15 to 27°C [60 to 80°F]. It is intended that this be a one-time determination of threshold values for data acquisition, or evaluation, or both. For field use, a portable acrylic rod (see Practice E2075) can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

A2.2 *Threshold of Detectability (aka Detection Threshold)*—To determine the detection threshold for AE examinations on fiberglass vessels, a sensor of the applicable type is mounted on one end of a 788 mm [31 in.] long, 38.1 mm [1.5 in.] diameter rod of cast acrylic material conforming to Specification D5436. Rod setup and sensor mounting shall be as specified in Practice E2075 (however the reference marks specified in Practice E2075 will not be used in this application). The detection threshold is 12 dB lower than the average measured amplitude of ten hits generated by a 0.3 mm [0.012 in.] Pentel pencil (2H) lead break at a distance of 610 mm [24 in.] from the sensor. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. This determination may be repeated with additional sensors, remounts as appropriate to confirm its reliability.

A2.3 *Reference Amplitude Threshold*—For large amplitude hits, the reference amplitude threshold shall be determined using a 300 by 5 by 2 cm [118 by 2 in. by 0.8 in.] clean, mild steel bar. The bar shall be supported at each end on elastomeric, or similar, isolating pads. The reference amplitude threshold is defined as the average measured amplitude of ten hits generated by a 0.3 mm [0.012 in.] Pentel pencil (2H) lead break at a distance of 210 cm [83 in.] from the sensor. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. The sensor shall be mounted 30 cm [12 in.] from the end of the bar on the 5 cm [2 in.] wide surface.

A2.4 *Typical Attenuation*—Table A2.1 shows signal amplitude values for various distances along a cast acrylic rod of the kind described in A2.2 and Practice E2075. These are values for a sensor containing a piezoelectric crystal often used for

TABLE A2.1 Decibel Calibration Values

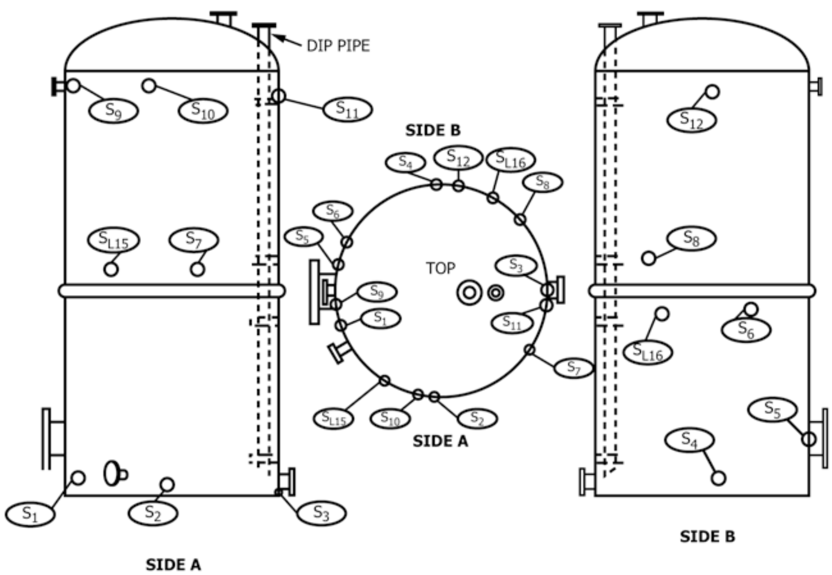
Distance of Pentel Break from Sensor	Typical Decibel Value
100 mm [4 in.]	82.5
150 mm [6 in.]	80.5
300 mm [12 in.]	73.5
450 mm [18 in.]	66.5
600 mm [24 in.]	60.0

this kind of test. The decibel numbers in Table A2.1 are dB_{AE} as defined in Terminology E1316. The numbers in this table are indicative of what may be expected when using the cast acrylic rod in accordance with A2.2, but these numbers shall not be taken as a substitute for performing the procedure.

A2.5 *Duration Criterion N_D—The Duration Criterion N_D shall be determined either before or after the examination using a 0.3 mm [0.012 in.] Pentel pencil (2H) lead broken on the surface of the vessel. This determination is made separately on each vessel examined. All lead breaks shall be done at an angle of approximately 30° to the test surface with a 2.5 mm [0.1 in.] lead extension. Measurement points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid (if applicable) and away from manways, nozzles, etc. A sensor shall be mounted at each measurement point and two measurements shall be carried out at each location. One measurement shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line 45° to the direction of the first measurement. Lead breaks shall be at a distance from the measurement point so as to provide an amplitude decibel value Am midway between the threshold of detectability and the Reference Amplitude Threshold. The Duration Criterion at each measurement point is defined as one hundred and thirty times the average duration per lead break from ten 0.3 mm [0.012 in.] Pentel pencil (2H) lead breaks at each of the two lead break locations. When applying the Duration Criterion, the value which is representative of the region where activity is observed should be used.*

A3. SENSOR PLACEMENT GUIDELINES

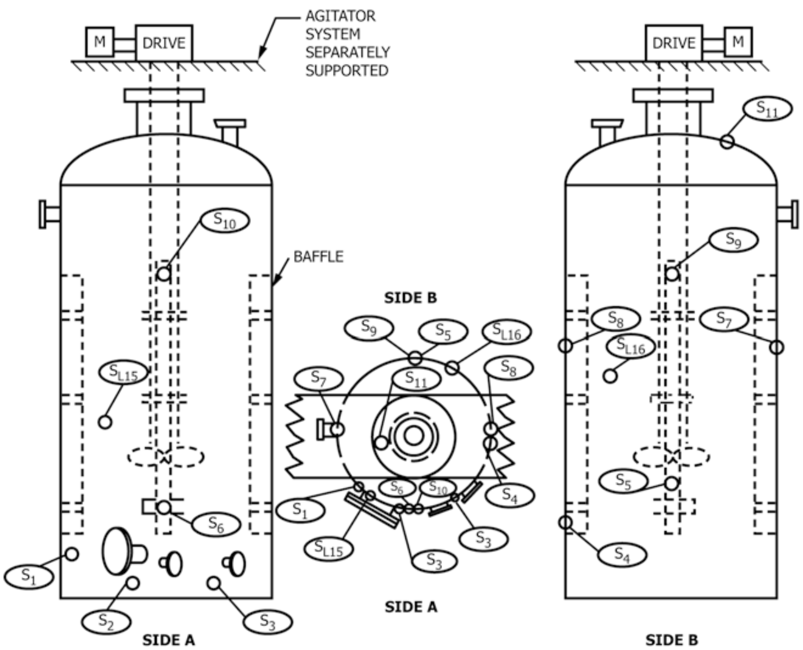
See Figs. A3.1-A3.6.



NOTE 1—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell.

NOTE 2—The secondary bond joint areas are suspect, for example, nozzles, manways, shell-butt joint, etc. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from intersection with shell and below. The shell-butt joint region is important. Locate the two high-frequency sensors up to 180° apart—one above and one below the joint.

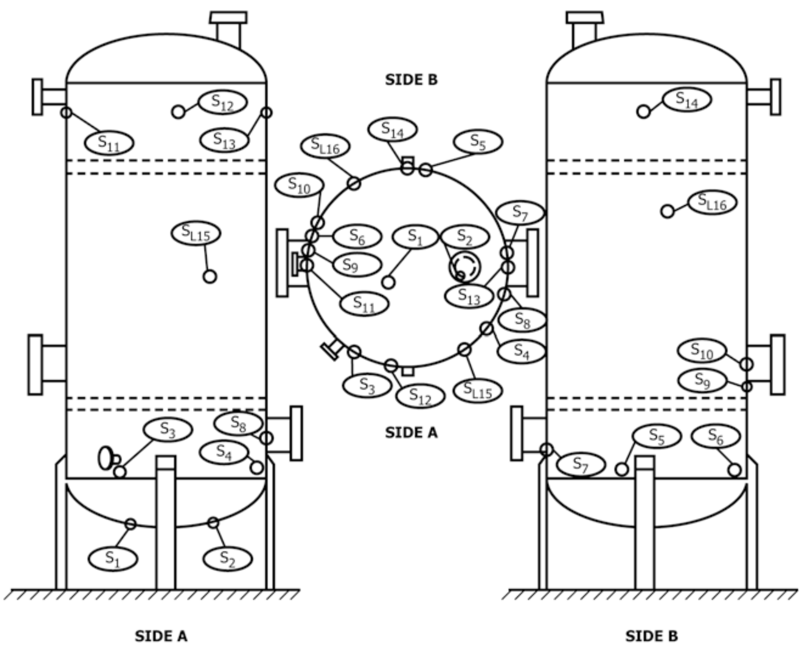
FIG. A3.1 Case I—Atmospheric Vertical Tank



NOTE 1—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle areas plus the knuckle region are covered.

NOTE 2—The secondary bond joint areas are suspect, for example, nozzles, manways, and baffle attachments to shell. See the last sentence of one above for bottom region coverage in this example. Note sensor adjacent to agitator shaft-top manway. This region should be checked with agitator on.

FIG. A3.2 Case II—Atmospheric Vertical Tank

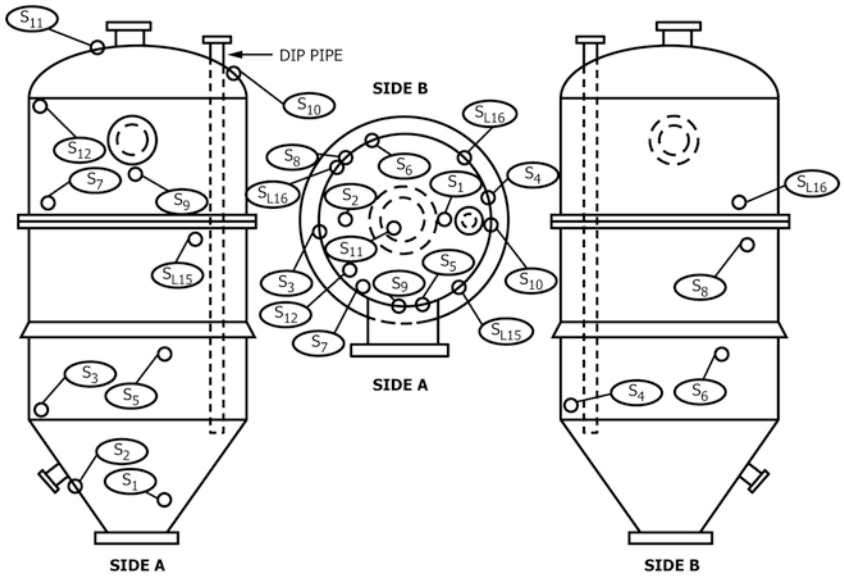


NOTE 1—The bottom head is highly stressed. Locate two sensors approximately as shown.

NOTE 2—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell. The top knuckle region is similarly treated.

NOTE 3—The secondary bond areas are suspect, that is, nozzles, manways, and leg attachments. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from the intersection with shell and below. For leg attachments, therefore should be a sensor within 300 mm [12 in.] of the shell-leg interface.

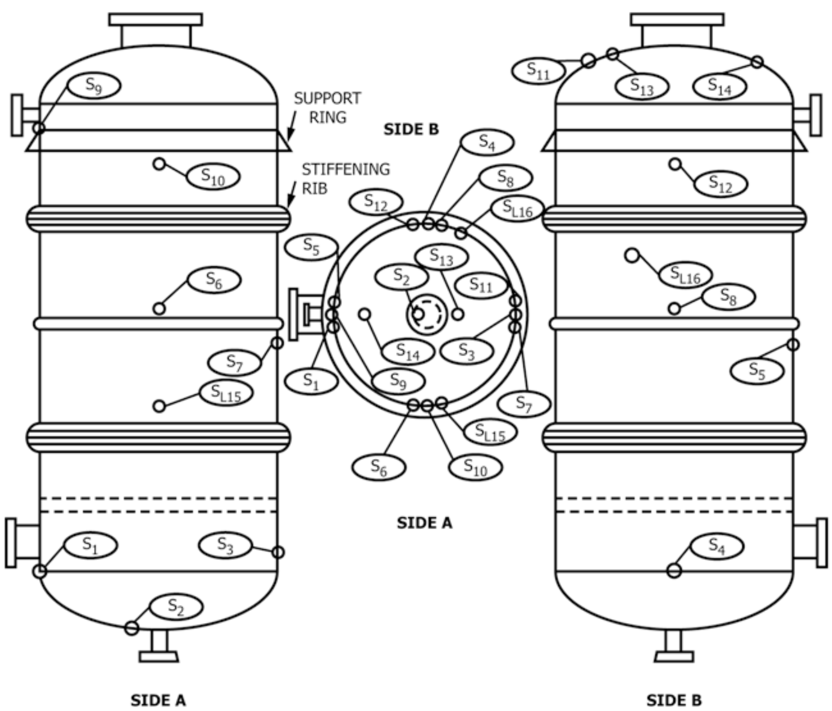
FIG. A3.3 Case III—Atmospheric-Pressure Vessel Tank



NOTE 1—The secondary bond-joint areas are suspect, that is, nozzles, manways, and body flanges. Particularly critical in this tank are the bottom manway and nozzle. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from intersection with shell and below. The bottom flange in this example is covered by a sensor 75 to 150 mm [3 to 6 in.] above the manway.

NOTE 2—The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, that is, approximately every 90° and 75 to 150 mm [6 to 12 in.] away from knuckle on shell.

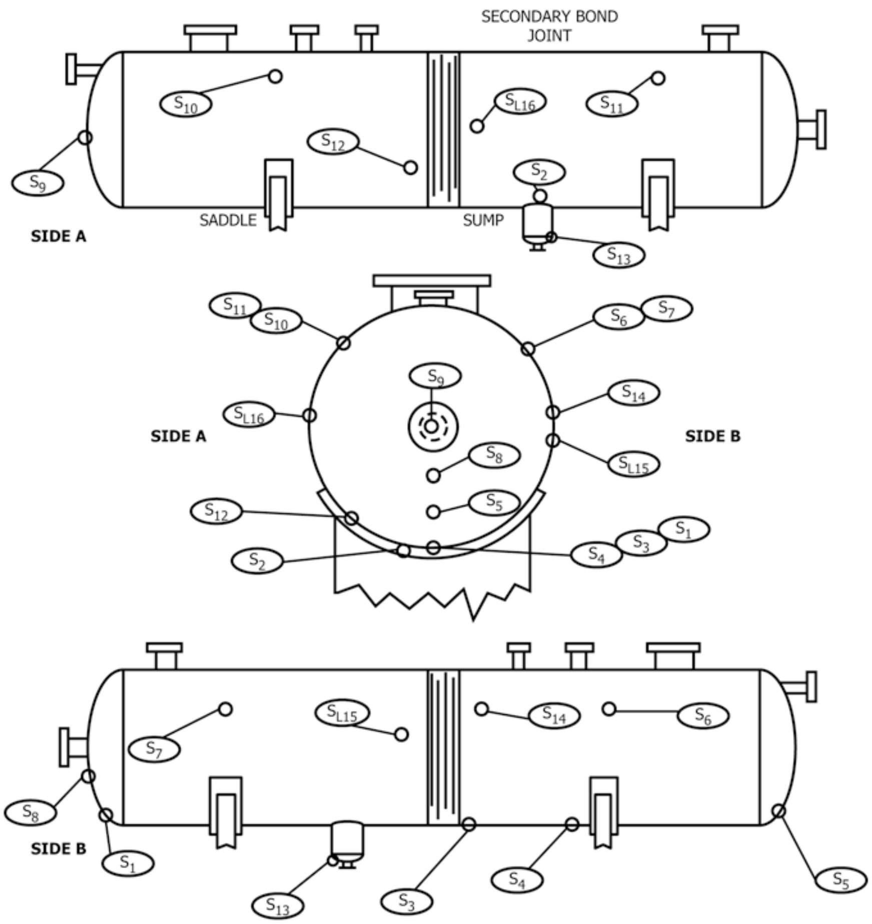
FIG. A3.4 Case IV—Atmospheric-Pressure Vertical Tank



NOTE 1—The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, that is, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell.

NOTE 2—The secondary bond-joint areas are critical, for example, nozzles, manways, and shell-butt joint. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from the intersection with the shell (or head) and below, where possible. The shell butt joint region is important. Locate sensors up to 180° apart where possible and alternately above and below joint.

FIG. A3.5 Case V—Atmospheric-Vacuum Vertical Tank



NOTE 1—The discontinuity stresses at the intersection of the heads and the shell in the bottom region are important. Sensors should be located to detect structural problems in these areas.

NOTE 2—The secondary bond-joint areas are suspect, for example, shell-butt joint, nozzles, manways, and sump. The preferred sensor location is 75 to 150 mm [3 to 6 in.] from intersecting surfaces of revolution. The shell butt-joint region is important. Locate the two high-frequency sensors up to 180° apart—one on either side of the joint.

FIG. A3.6 Case VI—Atmospheric-Pressure Horizontal Tank

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 This practice was rewritten from the "Recommended Practice for Acoustic Emission Testing of Fiberglass Tanks/ Vessels," which was developed by the Committee on Acoustic Emission from Reinforced Plastics (CARP) and published by the Reinforced/Composites Institute of the Society of the Plastics Industry (SPI).

X1.2 The CARP Recommended Practice has been used successfully on numerous applications.

X1.3 Criteria for evaluating the condition of FRP tanks and the need for secondary inspection were established while working with AE equipment, characteristics, and setup conditions listed in Table X1.1.

X1.4 Acceptance criteria are found in Table X1.2.

TABLE X1.1 Acoustic Emission Equipment, Characteristics, and Setup Conditions

Sensors	–77 dBV ref. 1V/ubar, at approximately 150 kHz
Couplant	silicone grease
Preamplifier gain	40 dB (X100)
Preamplifier filter	100 to 300 kHz bandpass
Power/signal cable length	<150 m [500 ft]
Low-amplitude threshold	46 dB_{AE}
High-amplitude threshold	76 dB_{AE}
Signal processor filter	100 to 300 kHz bandpass
Dead time	10 ms
Background noise	<40 dB_{AE}
Sensitivity check	>80 dB_{AE}

TABLE X1.2 Acceptance Criteria

NOTE 1—An acceptable vessel must meet all of the following criteria. Underlined criteria carry the greatest weight. Background noise must be properly discounted when applying acceptance criteria.

	Tanks (internal pressure no greater than 0.1 MPa absolute [14.5 psia] above the static pressure due to internal contents, or vacuum with differential pressure no greater than 0.1 MPa [14.5 psi])		Pressure Vessels (internal pressure no greater than 1.73 MPa absolute [250 psia] above the static pressure due to internal contents)[A]	Significance of Criterion
	First Filling	Subsequent Fillings	Subsequent Loadings	
Emissions during hold	No hits having an amplitude greater than A_m beyond 2 min[B]	None beyond 2 min	None beyond 2 min	Measure of continuing permanent damage[C]
Felicity ratio	Not applicable	Greater than 0.95	Greater than 0.95	Measure of severity of previously induced damage
Cumulative Duration, N_D[D]	Less than N_D	Less than $N_D/2$	Less than $N_D/2$	Measure of overall damage during a load cycle
High amplitude hits	Less than 5	None	Less than 5	Measure of high energy microstructural failures. This criterion is often associated with fiber breakage.

[A] Above the static pressure due to the internal contents.
[B] Decibel value A_m as defined in A2.5.
[C] Permanent damage may include microcracking, debonding, and fiber pull-out.
[D] Varies with instrumentation manufacturer. See A2.5 for functional definition of N_D.

STANDARD PRACTICE FOR ACOUSTIC EMISSION EXAMINATION OF REINFORCED THERMOSETTING RESIN PIPE (RTRP)

(19) SE-1118/SE-1118M

(Identical with ASTM Specification E1118/E1118M-16.)

Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

1. Scope

1.1 This practice covers acoustic emission (AE) examination or monitoring of reinforced thermosetting resin pipe (RTRP) to determine structural integrity. It is applicable to lined or unlined pipe, fittings, joints, and piping systems.

1.2 This practice is applicable to pipe that is fabricated with fiberglass and carbon fiber reinforcements with reinforcing contents greater than 15 % by weight. The suitability of these procedures must be demonstrated before they are used for piping that is constructed with other reinforcing materials.

1.3 This practice is applicable to tests below pressures of 35 MPa absolute [5000 psia].

1.4 This practice is limited to pipe up to and including 0.6 m [24 in.] in diameter. Larger diameter pipe can be examined with AE, however, the procedure is outside the scope of this practice.

1.5 This practice applies to examinations of new or in-service RTRP.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.* For more specific safety precautionary information see 8.1.

2. Referenced Documents

2.1 *ASTM Standards:*

D883 Terminology Relating to Plastics

E543 Specification for Agencies Performing Nondestructive Testing

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E1106 Test Method for Primary Calibration of Acoustic Emission Sensors

E1316 Terminology for Nondestructive Examinations

E1781 Practice for Secondary Calibration of Acoustic Emission Sensors

E2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod

2.2 *ASNT Standards:*

ANSI/ASNT CP-189 Personnel Qualification and Certification in Nondestructive Testing

ASNT SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

2.3 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Test Personnel

2.4 *ISO Documents*

ISO 9712 Non-destructive Testing—Qualification and Certification of NDT Personnel

3. Terminology

3.1 Complete glossaries of terms related to plastics and acoustic emission will be found in Terminologies D883 and E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *component and assembly proof testing*—a program of tests on RTRP components designed to assess product quality in a manufacturer's plant, at the installation site, or when taken out of service for retesting. An assembly is a shippable unit of factory-assembled components.

3.2.2 *count value* N_c—an evaluation criterion based on the total number of AE counts. (See A2.6.)

3.2.3 *diameter to thickness ratio (d/t)*—equal to $\frac{D_o + D_i}{2t}$ where (D_o) is the outside pipe diameter, (D_i) is the inside pipe diameter, and (t) is the wall thickness, as measured in a section of straight pipe.

3.2.4 *high-amplitude threshold*—a threshold for large amplitude events. (See A2.3.)

3.2.5 *in-service systems testing*—a program of periodic tests during the lifetime of an RTRP system designed to assess its structural integrity.

3.2.6 *low-amplitude threshold*—the threshold above which AE counts (N) are measured. (See A2.2.)

3.2.7 *manufacturers qualification testing*—a comprehensive program of tests to confirm product design, performance acceptability, and fabricator capability.

3.2.8 *operating pressure*—pressure at which the RTRP normally operates. It should not exceed design pressure.

3.2.9 *qualification test pressure*—a test pressure which is set by agreement between the user, manufacturer, or test agency, or combination thereof.

3.2.10 *rated pressure*—a nonstandard term used by RTRP pipe manufacturers as an indication of the maximum operating pressure.

3.2.11 *RTRP*—Reinforced Thermosetting Resin Pipe, a tubular product containing reinforcement embedded in or surrounded by cured thermosetting resin.

3.2.12 *RTRP system*—a pipe structure assembled from various components that are bonded, threaded, layed-up, etc., into a functional unit.

3.2.13 *signal value M*—a measure of the AE signal power (energy/unit time) which is used to indicate adhesive bond failure in RTRP cemented joints. (See A2.5.)

3.2.14 *system proof testing*—a program of tests on an assembled RTRP system designed to assess its structural integrity prior to in-service use.

4. Summary of Practice

4.1 This practice consists of subjecting RTRP to increasing or cyclic pressure while monitoring with sensors that are sensitive to acoustic emission (transient stress waves) caused by growing flaws. Where appropriate, other types of loading may be superposed or may replace the pressure load, for example, thermal, bending, tensile, etc. The instrumentation and techniques for sensing and analyzing AE data are described.

4.2 This practice provides guidelines to determine the location and severity of structural flaws in RTRP.

4.3 This practice provides guidelines for AE examination of RTRP within the pressure range stated in 1.3. Maximum test pressure for RTRP will be determined upon agreement among user, manufacturer, or test agency, or combination thereof. The test pressure will normally be 1.1 multiplied by the maximum operating pressure.

5. Significance and Use

5.1 The AE examination method detects damage in RTRP. The damage mechanisms detected in RTRP are as follows: resin cracking, fiber debonding, fiber pullout, fiber breakage, delamination, and bond or thread failure in assembled joints. Flaws in unstressed areas and flaws which are structurally insignificant will not generate AE.

5.2 This practice is convenient for on-line use under operating conditions to determine structural integrity of in-service RTRP usually with minimal process disruption.

5.3 Flaws located with AE should be examined by other techniques; for example, visual, ultrasound, and dye penetrant, and may be repaired and retested as appropriate. Repair procedure recommendations are outside the scope of this practice.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, ASNT SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.4 *Timing of Examination*—The timing of examination shall be in accordance with Section 11 unless otherwise specified.

6.5 *Extent of Examination*—The extent of examination shall be in accordance with 9.4 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 12 unless otherwise specified. Since acceptance criteria are not specified in this standard, they shall be specified in the contractual agreement.

6.7 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7. Instrumentation

7.1 The AE instrumentation consists of sensors, signal processors, and recording equipment. Additional information on AE instrumentation can be found in Practice E750.

7.2 Instrumentation shall be capable of recording AE counts and AE events above the low-amplitude threshold. It shall also record events above the high-amplitude threshold as well as signal value *M* within specific frequency ranges, and have sufficient channels to localize AE sources in real time. It may incorporate (as an option) peak amplitude detection. An AE event amplitude measurement is recommended for sensitivity verification (see Annex A2). Amplitude distributions are recommended for flaw characterization. It is preferred that the AE instrumentation acquire and record count, event, amplitude, and signal value *M* information on a per channel basis. The AE instrumentation is further described in Annex A1.

7.3 Capability for measuring parameters such as time and pressure shall be provided. The pressure-load shall be continuously monitored to an accuracy of ±2 % of the maximum test value.

8. Test Preparations

8.1 *Safety Precautions*—All plant safety requirements unique to the test location shall be met.

8.1.1 Protective clothing and equipment that is normally required in the area in which the test is being conducted shall be worn.

8.1.2 A fire permit may be needed to use the electronic instrumentation.

8.1.3 Precautions shall be taken against the consequences of catastrophic failure when testing, for example, flying debris and impact of escaping liquid.

8.1.4 Pneumatic testing is extremely dangerous and shall be avoided if at all possible.

8.2 *RTRP Conditioning:*

8.2.1 If the pipe has not been previously loaded, no conditioning is required.

8.2.2 If the pipe has been previously loaded, one of two methods shall be used. For both methods, the maximum operating pressure-load in the pipe since the previous examination must be known. If more than one year has elapsed since the last examination, the maximum operating pressure-load during the past year can be used. (See 11.2.3.)

8.2.2.1 Option I requires that the test shall be run from 90 up to 110 % of the maximum operating pressure-load. In this case no conditioning is required. (See Fig. 7.) If it is not possible to achieve over 100 % of the maximum operating pressure-load, Option II may be used.

8.2.2.2 Option II requires that the operating pressure-load be reduced prior to testing in accordance with the schedule shown in Table 1. In this case, the maximum pressure-load need be only 100 % of the operating pressure (see Fig. 8).

8.3 *RTRP Pressurizing-Loading*—Arrangements should be made to pressurize the RTRP to the appropriate pressure-load. Liquid is the preferred pressurizing medium. Holding pressure-load levels is a key aspect of an acoustic emission examination. Accordingly, provision shall be made for holding the pressure-load at designated check points.

8.4 *RTRP Support*—The RTRP system shall be properly supported.

8.5 *Environmental*—The normal minimum acceptable RTRP wall temperature is 4°C [40°F].

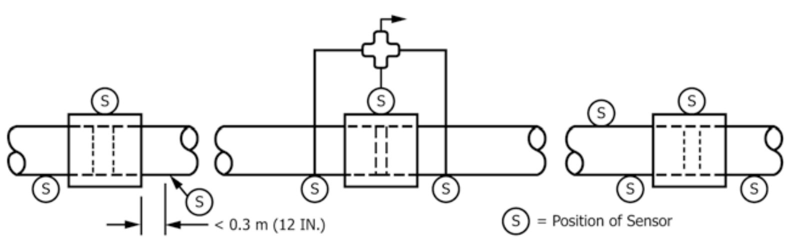
8.6 *Noise Reduction*—Noise sources in the examination frequency and amplitude range, such as malfunctioning pumps or valves, movement of pipe on supports, or rain, must be minimized since they mask the AE signals emanating from the pipe.

8.7 *Power Supply*—A stable grounded power supply, meeting the specification of the instrumentation, is required at the test site.

8.8 *Instrumentation Settings*—Settings will be determined in accordance with Annex A2.

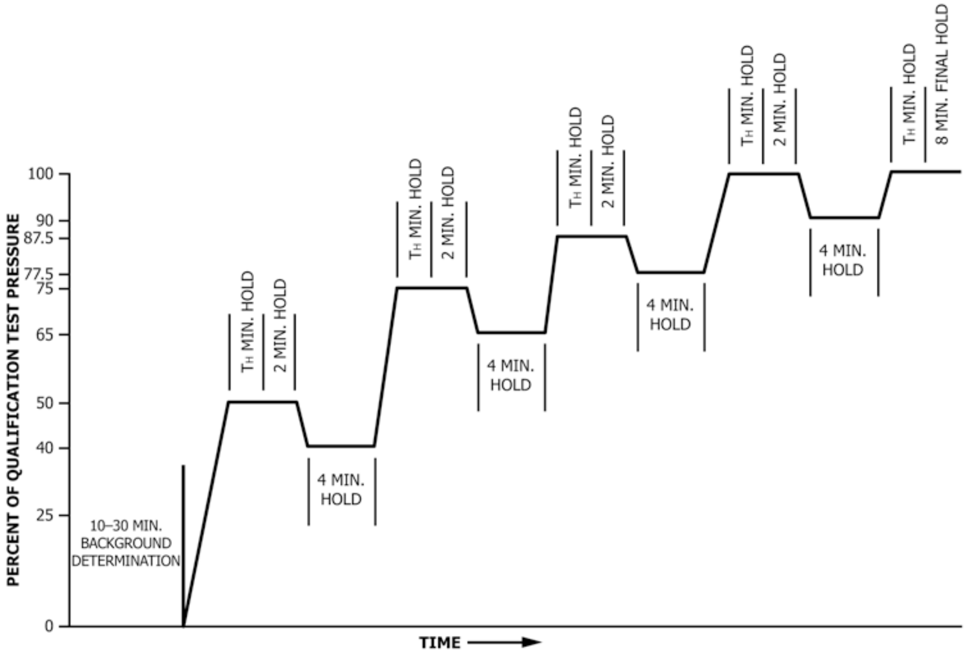
9. Sensors

9.1 *Sensor Mounting*—Refer to Guide E650 for additional information on sensor mounting. Location and spacing of the sensors are discussed in 9.4. Sensors shall be placed in the designated locations with a couplant interface between sensor



NOTE 1—A maximum of three sensors can be connected into one channel.

FIG. 1 Typical Sensor Positioning for Zone Location



NOTE 1—Diameter to thickness ratio (d/t) ≥ 16, T_H = 2 min. Diameter to thickness ratio (d/t) < 16, T_H = 4 min.

FIG. 2 RTRP Manufacturer's Qualification Test, Pressurizing Sequence

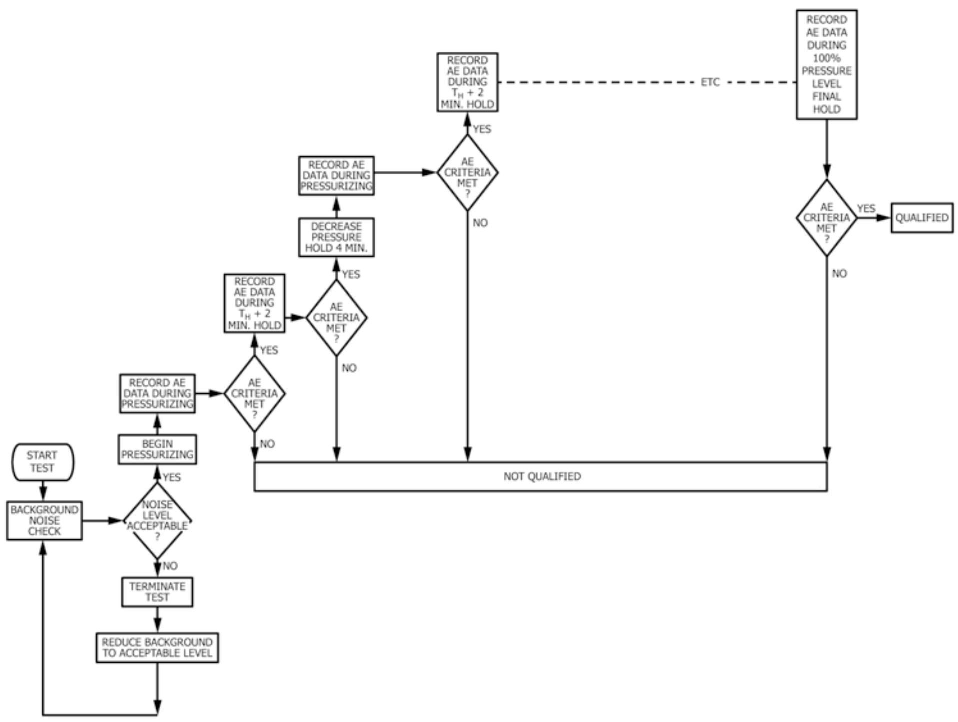
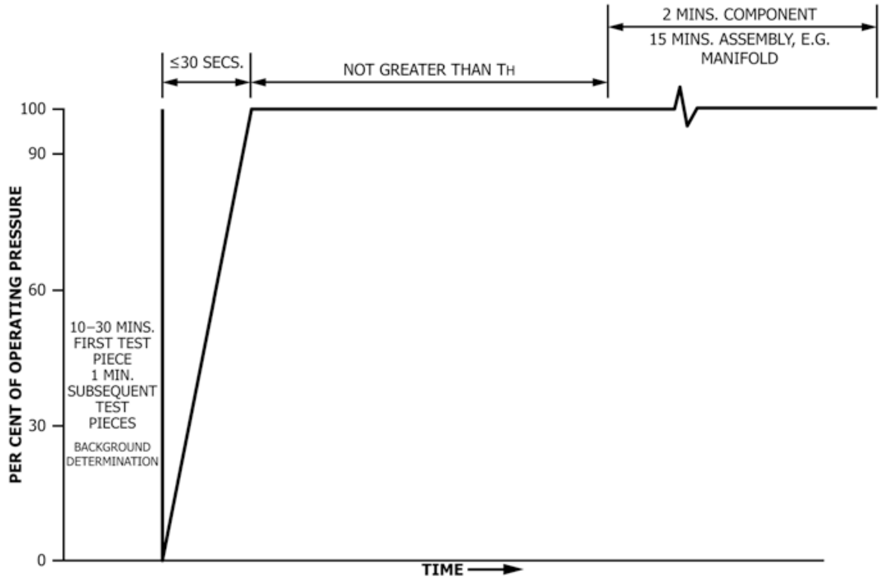


FIG. 3 AE Test Algorithm—Flow Chart, RTRP Qualification Test (see Fig. 2**)**

and test article. One recommended couplant is silicone-stopcock grease. Care must be exercised to ensure that adequate couplant is applied. Sensors shall be held in place utilizing methods of attachment which do not create extraneous signals. Methods of attachment using strips of pressure-sensitive tape, stretch fabric tape with hook and loop fastener, or suitable adhesive systems may be considered. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method should provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or causing loss of coupling.



NOTE 1—Diameter to thickness ratio (d/t) ≥ 16, T_H = 2 min. Diameter to thickness ratio (d/t) < 16, T_H = 4 min.

FIG. 4 RTRP Component and Assembly Proof Test, Pressurizing Sequence

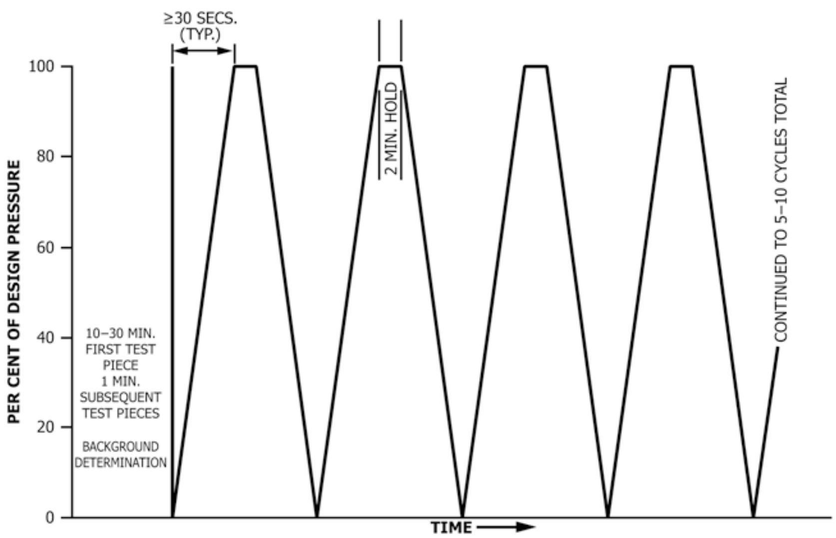


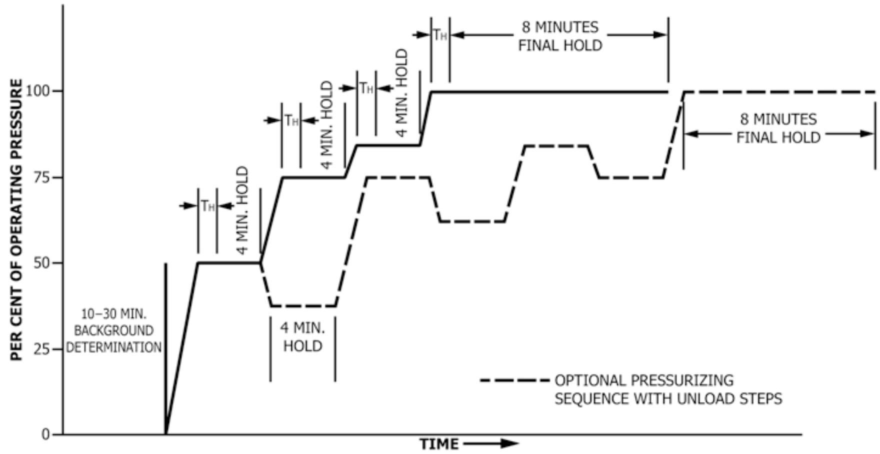
FIG. 5 RTRP Systems Proof Test, Pressurizing Sequence

9.2 *Surface Contact*—Reliable coupling between the sensor and pipe surface shall be ensured and the surface of the pipe in contact with the sensor shall be clean and free of particulate matter. Sensors should be mounted directly on the RTRP surface unless integral waveguides shown by test to be satisfactory are used. Preparation of the contact surface shall be compatible with both sensor and structure modification requirements. Possible causes of signal loss are coatings such as paint and encapsulants, inadequate sensor contact on curved surfaces, off-center sensor positioning and surface roughness at the contact area.

9.3 *Zone Location*—Several high-frequency sensors [100 to 250 kHz] are used for zone location of emission sources. Attenuation is greater at higher frequencies requiring closer spacing of sensors. Zones may be refined if events hit more than one sensor. (See Fig. 1 and Annex A3.)

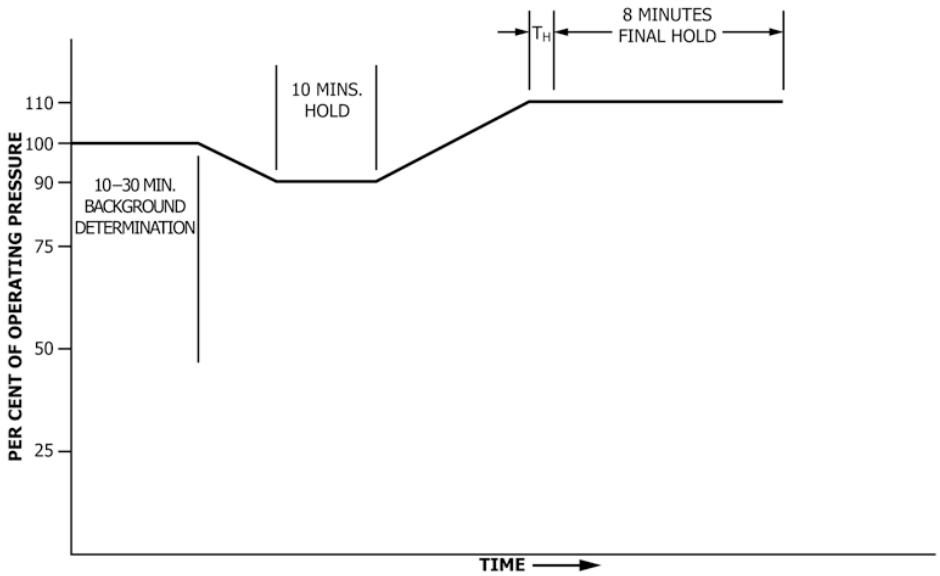
9.4 *Locations and Spacings*—Sensor locations on the RTRP are determined by the need to detect structural flaws at critical sections, for example, joints, high-stress areas, geometric discontinuities, repaired regions, and visible defects. The number of sensors and their location is based on whether full coverage or random sampling of the system is desired. For full coverage of the RTRP, excluding joints, sensor spacings of 3 m [10 ft] are usually suitable.

9.4.1 *Attenuation Characterization*—Signal propagation losses shall be determined in accordance with the following procedure. This procedure provides a relative measure of the attenuation, but may not be representative of a genuine event.



NOTE 1—Diameter to thickness ratio (d/t) ≥ 16, T_H = 2 min. Diameter to thickness ratio (d/t) < 16, T_H = 4 min.

FIG. 6 RTRP Systems Proof Test, Alternate Pressurizing Sequence



NOTE 1—Diameter to thickness ratio (d/t) ≥ 16, T_H = 2 min. Diameter to thickness ratio (d/t) < 16, T_H = 4 min.

FIG. 7 RTRP System In-Service Test, Option I, Pressurizing Sequence

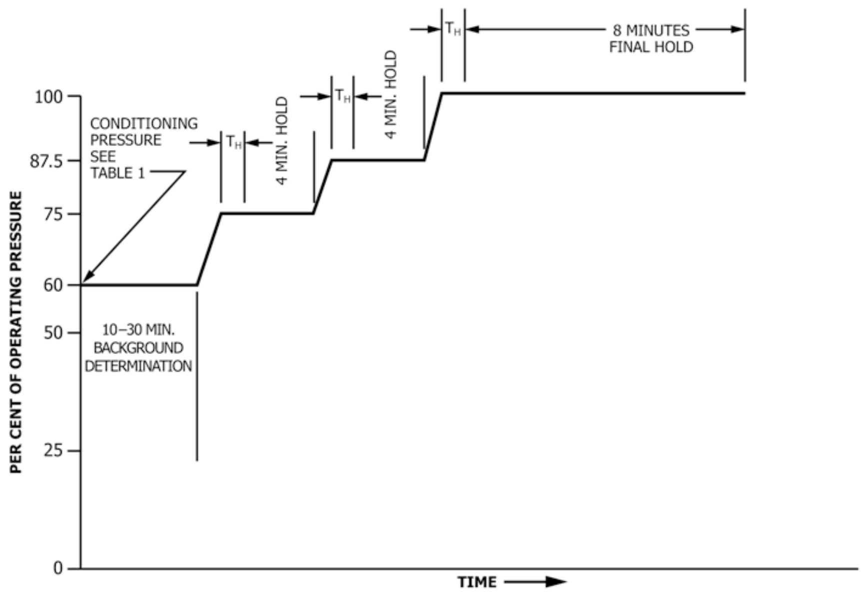
TABLE 1 Option II Requirements for Reduced Operating Pressure-Load Immediately Prior to Testing

Percent of Operating Pressure or Load, or Both	Time at Reduced Pressure or Load, or Both
10 or less	12 h
20	18 h
30	30 h
40	2 days
50	4 days
60	7 days

It should be noted that the peak amplitude from a mechanical pencil lead break may vary with surface hardness, resin condition, cure, and test fluid. For pressure tests, the attenuation characterization shall be carried out with the pipe full of the test fluid.

9.4.1.1 Select a representative region of the RTRP. Mount an AE sensor and locate points at distances of 150 mm [6 in.] and 300 mm [12 in.] from the center of the sensor along a line parallel to the axis of the pipe. Select two additional points on the surface of the pipe at 150 mm [6 in.] and 300 mm [12 in.] along a helix line inclined 45° to the direction of the original points. At each of the four points, break 0.3 mm [0.012 in.] 2H leads and record peak amplitude. All lead breaks shall be done at an angle of approximately 30° to the test surface with a 2.5-mm [0.1-in.] lead extension (see Guide E976). The data shall be retained as part of the original experimental record.

9.4.2 *Sensor Location*—Severe attenuation losses occur at unreinforced adhesive joint lines and across threaded joints.



NOTE 1—Diameter to thickness ratio (d/t) ≥ 16, T_H = 2 min. Diameter to thickness ratio (d/t) < 16, T_H = 4 min.

FIG. 8 RTRP System In-Service Test, Option II, Pressurizing Sequence

Accordingly, sensors should be located on either side of such interfaces. The sensor spacing on straight sections of pipe shall be not greater than 3 × the distance at which the recorded amplitude from the attenuation characterization equals the low-amplitude threshold. The spacing distance shall be measured along the surface of the pipe.

9.4.3 Sensor zone location guidelines for the following RTRP configurations are given in Annex A3. Other configurations require an agreement among the user, manufacturer, or test agency, or combination thereof.

9.4.3.1 **Case I:** *Coupled*—Cemented or threaded joint pipe system. (The sensor on the coupling is normally required because the adhesive is highly attenuative.)

9.4.3.2 **Case II:** *Bell and Spigot*—Cemented or threaded joint pipe system.

9.4.3.3 **Case III:** *Hand Lay-up*—Field fabricated secondary bond mat joint pipe system.

9.4.3.4 **Case IV:** *Flanged Joint Pipe System.*

10. Instrumentation System Performance Check

10.1 *Sensor Coupling and Circuit Continuity Verification*—Verification shall be performed following sensor mounting and system hookup. The peak amplitude response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source (see Annex A2) should be taken prior to the examination. The peak amplitude of the simulated event generated at 150 mm [6 in.] from each sensor should not vary more than 6 dB from the average of all the sensors. Any sensor-preamplifier combination failing this check should be investigated and replaced or repaired as necessary.

10.2 *Background Noise Check*—A background noise check is required to identify and determine level of spurious signals. This is done following completion of the verification described in 10.1 and prior to pressurizing the RTRP. A recommended time period is 10 to 30 min. A low level of background noise is important for conducting an examination and is particularly important for zone location. Continuous background noise at a level above the low amplitude threshold is unacceptable and must be reduced before conducting the examination.

11. Testing Procedure

11.1 *General Guidelines*—The RTRP is subjected to programmed increasing pressure-load levels to a predetermined maximum while being monitored by sensors that detect acoustic emission (stress waves) caused by growing structural flaws.

11.1.1 Load will normally be applied by internal pressurization of the pipe and this is the basis for the examination procedure outlined in this and following sections. Service conditions always include other kinds of significant loads. Such loads shall be included or simulated in the test and, where possible, should be applied in increments similar to the pressure.

11.1.2 With the exception of proof testing, pressurization rates of assembled pipe systems shall be controlled so as not to exceed a rate of 5 % (of operating pressure) per minute. Pressurizing rates for component and system proof testing (see 11.2) shall not exceed 100 % test pressure in 30 s. The desired pressure shall be attained with a liquid (see 8.1.3 and 8.1.4). A suitable calibrated gage shall be used to monitor pressure.

11.1.3 Background noise must be minimized and identified (see also 8.6 and 10.2). Excessive background noise is cause for suspension of pressurization. In the analysis of examination results, background noise that can be identified shall be separated out and properly discounted. Sources of background noise include the following: pumps, motors, meters and other mechanical devices, electromagnetic interference, movement on supports, and environmental factors such as rain, wind, etc.

11.2 *Pressurizing*—Four recommended pressurizing sequences are provided as follows:

1. Manufacturers Qualification Test
2. Component and Assembly (for example, Manifold) Proof Test
3. Systems Proof Test
4. System In-Service Test, Option I or Option II

The initial hold period in all cases is used to determine the background noise baseline. The data provides an estimate of the total background noise contribution during an examination. Intermittent and final load holds vary in accordance with the type of testing done; see the appropriate pressurizing sequence. The test shall be monitored continuously during the final hold periods.

11.2.1 *Manufacturers Qualification Testing*—The recommended pressurizing sequence is shown in Fig. 2. The test algorithm flow chart is shown in Fig. 4. The qualification test pressure shall be set by agreement between user, manufacturer, or test agency, or combination thereof.

11.2.2 *Proof Testing:*

11.2.2.1 *Component and Assembly Proof Test*—The recommended pressurizing sequence for RTRP component and assembly proof tests is shown in Fig. 4. For component proof tests, total hold periods may be reduced provided that no emissions are recorded for a 2-min period.

11.2.2.2 *Systems Proof Test*—The recommended pressurizing sequences are shown in Figs. 5 and 6.

11.2.3 *In-Service Testing:*

11.2.3.1 *System In-Service Test, Option I* (Preferred)—The recommended pressurizing sequence is shown in Fig. 7.

11.2.3.2 *System In-Service Test, Option II*—The recommended pressurizing sequence is shown in Fig. 8. It is to be used only in those cases in which overpressurization is not allowed.

11.2.4 *AE Test Algorithm-Flow Charts*—Charts similar to Fig. 3 can be developed for the other pressurization/load sequences.

11.3 *Felicity Ratio Determination*—The Felicity Ratio is determined from unload/reload cycles, for manufacturer qualification and proof testing. Following the unload, and during the reload, the Felicity ratio is obtained directly from the ratio of stress at the emission source at onset of significant emission to the previous maximum stress at the same point.

11.3.1 The Felicity ratio for in-service tests is obtained directly from the ratio of stress at the emission source at onset of significant emission to the previous maximum operating stress at the same point.

11.4 *Data Recording:*

11.4.1 Prior to an examination the signal propagation loss (attenuation) data, that is, amplitude as a function of distance from the signal source, shall be recorded in accordance with the procedure detailed in 9.4.1.

11.4.2 During an examination the sum of counts above the low-amplitude threshold from all channels shall be monitored and recorded. The location of each active zone shall be determined and recorded (see Annex A2). The signal value M shall be monitored and its maximum recorded (see Annex A2). The number of events that exceed the high-amplitude threshold shall be recorded. Channels that are active during load holds should be noted.

12. Interpretation of Results

12.1 *Test Termination*—Departure from a linear count-load relationship should signal caution. If the AE count rate increases rapidly with stress, the RTRP shall be unloaded and that examination terminated. A rapidly (exponentially) increasing count rate indicates uncontrolled, continuing damage and is indicative of impending failure.

12.2 *Significance of Data:*

12.2.1 Evaluation based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Pressurizing and other background noise will generally be at a minimum during a load hold. Emissions continuing during hold periods is a condition on which accept/reject criteria may be based.

12.2.2 The signal value M is a sensitive measure of superimposed subthreshold events which is particularly important for indicating adhesive bond failure in pipe joints. Signal values vary with instrument manufacturer. (See Annex A2.) Signal values which exceed a specified value of M is a condition on which accept/reject criteria may be based.

12.2.3 RTRP, particularly on first loading, tends to be noisy and, therefore, will generally require different interpretation from subsequent loadings.

12.2.4 Evaluation based on Felicity ratio is important for in-service RTRP. The Felicity ratio provides a measure of the severity for previously induced damage. The onset of *significant* emission for determining measurement of the Felicity ratio is a matter of experience. The following are offered as guidelines to determine if emission is significant:

12.2.4.1 More than 5 bursts of emission during a 10 % increase in load.

12.2.4.2 More than $N_c/25$ counts during a 10 % increase in load, where N_c is the count value defined in A2.6.

12.2.4.3 Emission continues at a load hold. For purposes of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

12.2.4.4 Felicity ratio is a condition on which accept/reject criteria may be based.

12.2.5 Evaluation based on high-amplitude events is important for new RTRP. These events are often associated with fiber breakage and are indicative of major structural damage. This condition is less likely to govern for in-service and previously loaded RTRP where emissions during a load hold and Felicity ratio generally are more important. High-amplitude events (above the high-amplitude threshold) is a condition on which accept/reject criteria may be based.

13. Report

13.1 The report shall include the following:

13.1.1 Complete identification of the RTRP, including material type, source, method of fabrication, manufacturer's name and code number, date and pressure-load of previous tests, and previous history.

13.1.2 Dimensioned sketch or manufacturer's drawing of the RTRP system showing sensor locations, including the results of sensor coupling and circuit continuity verification.

13.1.3 Test liquid employed.

13.1.4 Test liquid temperature.

13.1.5 *Test Sequence*—Pressurizing-loading rate, hold times, and hold levels.

13.1.6 Comparison of examination data with specified accept/reject criteria and an assessment of the location and severity of structural flaws based on the data.

13.1.7 Show on sketch (see 13.1.2) or manufacturer's drawing the location of any zones with AE activity exceeding acceptance criteria.

13.1.8 Any unusual effects or observations during or prior to the examination.

13.1.9 Dates of examination.

13.1.10 Name(s) of examiner(s).

13.1.11 *Instrumentation Description*—Complete description of AE instrumentation including manufacturer's name, model number, sensor type, system gain, serial numbers of equivalent, software title, and version number.

13.1.12 Permanent record of AE data, for example, signal value *M* versus time for zones of interest, total counts above the low-amplitude threshold versus time, number of events above the high-amplitude threshold, emissions during load holds, signal propagation loss (see 9.4.1).

14. Keywords

14.1 adhesive joints; Felicity effect; Felicity ratio; FRP pipe; load hold; RTRP; zone location

ANNEXES

(Mandatory Information)

A1. INSTRUMENTATION PERFORMANCE REQUIREMENTS

A1.1 AE Sensors

A1.1.1 *General*—AE sensors shall operate without electronic or other spurious noise above the low-amplitude threshold over a temperature range from 4 to 93°C [40 to 200°F], and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice or differential (anticoincident) element design, or both. Sensors shall have omnidirectional response in the plane of contact, with variations not exceeding 4 dB from the peak response.

A1.1.2 *Sensors*—Sensors shall have a resonant response between 100 and 200 kHz. Acceptance sensitivity range shall be established using a published procedure such as Test Method E1106 or Practice E1781.

NOTE A1.1—This method measures approximate sensitivity of the sensor. AE sensors used in the same examination should not vary in peak sensitivity more than 3 dB from the average. Additional information on AE sensor response can be found in Guide E976.

A1.1.3 *Signal Cable*—The signal cable from sensor to preamp shall not exceed 2 m [6 ft] in length and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the sensor housing, or a line-driving (matched impedance) sensor is used.

A1.1.4 *Couplant*—Commercially available couplants for ultrasonic flaw detection may be used. Frangible wax or quick-setting adhesives may be used, provided couplant sensitivity is no lower than with fluid couplants. Couplant selection should be made to minimize changes in coupling sensitivity during an examination. Consideration should be given to testing time and the surface temperature of the pipe.

A1.1.5 *Preamplifier*—The preamplifier should be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamp is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. The preamplifier band pass shall be consistent with the frequency range of the sensor and shall not attenuate the resonant frequency of the sensor.

A1.1.6 *Filters*—Filters shall be of the band pass or high-pass type, and shall provide a minimum of 24 dB per octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamp, or processor to limit frequency response. Filters or integral design characteristics, or both, shall ensure that the principal processing frequency from sensors is not less than 100 kHz.

A1.1.7 *Power-Signal Cable*—The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB/300 m [1000 ft] of cable length at 200 kHz. The recommended maximum cable length is 300 m [1000 ft] to avoid excessive signal attenuation. Digital or radio transmission of signals is allowed consistent with standard practice in transmitting those signal forms.

A1.1.8 *Main Amplifier*—The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range from 20 to 300 kHz, and temperature range from 4 to 50°C [40 to 120°F]. The main amplifier shall have adjustable gain, or an adjustable threshold for event detection and counting.

A1.1.9 *Main Processor:*

A1.1.9.1 *General*—The main processor(s) shall have a minimum of one active data processing circuit. If independent channels are used, the processor shall be capable of processing events and counts on each channel. Connecting sensors and preamplifiers in this manner may result in sensitivity losses of

6 - 8dB on these channels. These losses should be measured and compensated for in the channel settings.

(1) Total counts shall be processed from all channels. Signal values shall also be processed from all channels.

A1.1.9.2 *Peak Amplitude Detection*—If peak-amplitude detection is practiced, comparative calibration must be established in accordance with the requirements of Annex A2. Usable dynamic range shall be a minimum of 60 dB with 2-dB resolution. Not more than 2-dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or decibels, but must be referenced to a fixed gain output of the system (sensor or preamp).

A1.1.9.3 *Signal Outputs and Recording*—The processor as a minimum shall provide outputs for permanent recording of total counts above low-amplitude threshold, total events above the high-amplitude threshold, and signal value *M* for all channels, and events by channel (zone location). A system schematic is shown in Fig. A1.1.

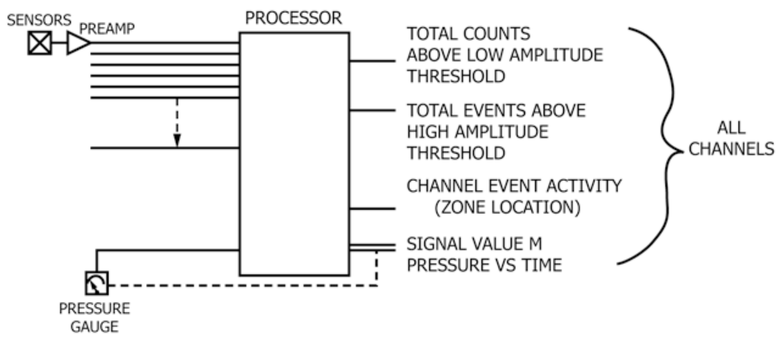


FIG. A1.1 Sample Schematic of AE Instrumentation

A2. INSTRUMENT SETTINGS

A2.1 *General*—The performance and threshold definitions vary for different types of acoustic emission equipment. Processing of parameters such as amplitude and energy varies from manufacturer to manufacturer, and from model to model by the same manufacturer. This annex defines procedures for determining the low-amplitude threshold, high-amplitude threshold, count value N_c, and signal value *M*.

A2.1.1 The procedures defined in this annex are intended for baseline instrument settings at 15 to 27°C [60 to 80°F]. It is recommended that instrumentation users develop instrument setting techniques along the lines outlined in this annex. For field use, a portable acrylic rod (Practice A7) can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

A2.2 *Low-Amplitude Threshold*—(or system threshold). The threshold setting shall be determined using an acrylic rod, no less than 94 cm [37 in.] long by 3.8 cm [1.5 in.] in diameter, in a variant on Practice E2075. The threshold setting is defined as the average measured amplitude of ten events generated by a 0.3 mm [0.012 in.] mechanical pencil (2H) lead break at a distance of 76 cm [30 in.] from the sensor. All lead breaks shall be mounted on the end of the rod as described in Practice E2075. This standard differs from Practice E2075 insofar as the source-sensor distance is greater and the rod is longer. These are necessary to get sufficient attenuation while avoiding end effects. The other details of Practice E2075 should be observed.

A2.3 *High-Amplitude Threshold*—For large amplitude events, the high-amplitude threshold shall be determined using a 300 cm by 5 cm by 2-cm [10 ft by 2 in. by 0.75 in.] clean, mild steel bar. The bar shall be supported at each end on elastomeric, or similar, isolating pads. The high-amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm [0.012 in.] mechanical pencil (2H) lead break at a distance of 210 cm [7 ft] from the sensor. The sensor shall be mounted 30 cm [12 in.] from the end of the bar on the 5-cm [2 in.] wide surface.

A2.4 *AE Decibel Calibration*—All AEDC Instruments used with this practice shall meet the Terminology E1316, Section B definition of dB_{AE}. This can be verified using standard AE laboratory or field simulators or calibrators.

A2.5 *Signal Value M, Electronic Calibration* — Signal value *M* is an indicator of adhesive bond failure. It is a continuous measurement resulting from ongoing averaging of the input signal over a 5 to 10-ms period. The reference signal value M_o is the instrument output which is obtained from an electronically generated input of a 10-ms duration, 150-kHz sine wave with a peak voltage five times the low-amplitude threshold. Input of a 150-kHz sine burst of 100-µs duration at peak voltage 50 times the low-amplitude threshold should result in a signal value no greater than 0.1 M_o. For instruments which include a filter in the main processor, the frequency of the sine burst may be at the center frequency of the filter, provided it is between 100 and 200 kHz. Different techniques are used by different instrument manufacturers for measuring the signal value. The units of the signal value will vary depending upon the techniques and instrument that is used.

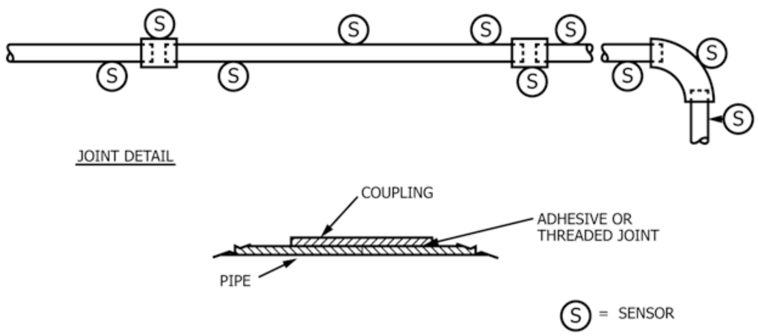
A2.6 *Count Value* N_c—The count value N_c shall be determined either before or after the examination using a 0.3 mm [0.012 in.] mechanical pencil (2H) lead broken on the surface of the pipe. All lead breaks shall be done at an angle of approximately 30° to the test surface with a 2.5-mm [0.1 in.] lead extension. Calibration points shall be chosen at the midpoint of the pipe and on couplings and fittings, so as to be representative of different constructions and thicknesses, and should be performed with the pipe full of test fluid.

A2.6.1 A sensor shall be mounted at each calibration point and two calibrations shall be carried out at each location. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45° to the direction of the first calibration. Lead breaks shall be at a distance from the calibration point so as to provide an amplitude decibel value midway between the low-amplitude threshold (see A2.2) and high-amplitude threshold (see A2.3).

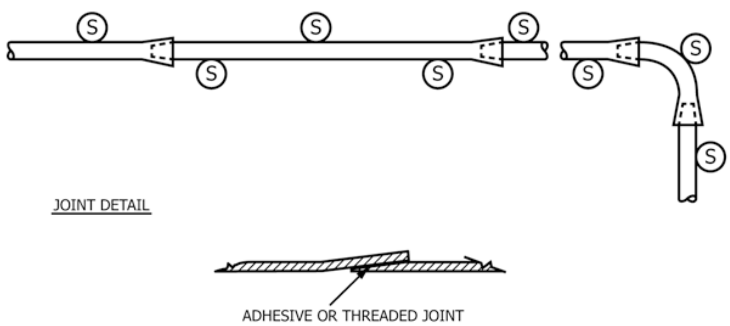
A2.6.2 The count value N_c at each calibration point is defined as five times the total counts recorded from 13 lead breaks at each of the two lead break locations.

A2.6.3 When applying the count evaluation, the count value, which is representative of the region (construction and thickness) where activity is observed, should be used.

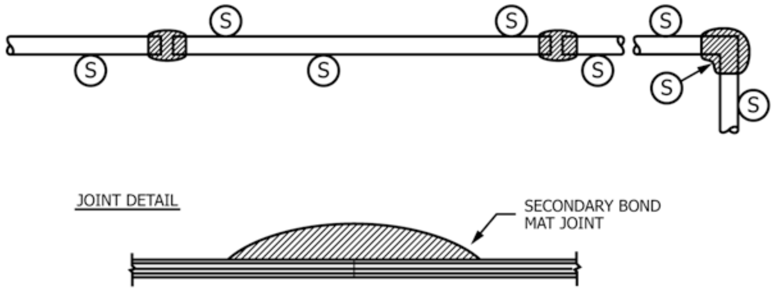
A3. SENSOR PLACEMENT GUIDELINES



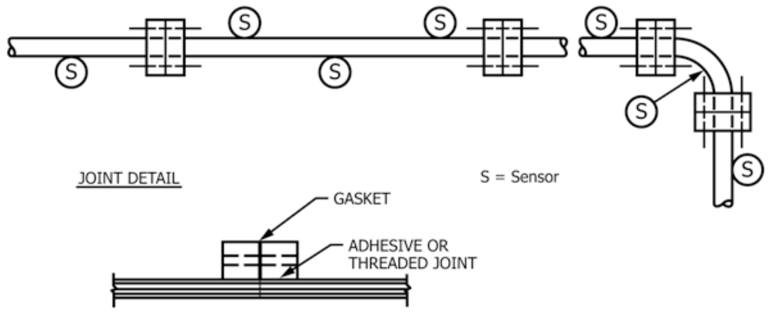
A3.1 *Case I Coupled*—Cemented or threaded joint system.



A3.2 *Case II Bell and Spigot*—Cemented or threaded joint system.



A3.3 *Case III Hand Up*—Field fabricated secondary bond mat joint pipe system.



A3.4 *Case IV*—Flanged joint pipe system.

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 This practice was rewritten from the "Recommended Practice for Acoustic Emission Testing of Reinforced Thermosetting Resin Pipe," which was developed by the Committee on Acoustic Emission from Reinforced Plastics (CARP) and published by the Reinforced Plastics/Composites Institute of the Society of the Plastics Industry (SPI).

X1.2 The CARP Recommended Practice has been used successfully on numerous applications.

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STANDARD PRACTICE FOR CONTINUOUS MONITORING OF ACOUSTIC EMISSION FROM METAL PRESSURE BOUNDARIES

(19) SE-1139/SE-1139M

(Identical with ASTM Specification E1139/E1139M-17.)

Standard Practice for Continuous Monitoring of Acoustic Emission from Metal Pressure Boundaries

1. Scope

1.1 This practice provides guidelines for continuous monitoring of acoustic emission (AE) from metal pressure boundaries in industrial systems during operation. Examples are pressure vessels, piping, and other system components which serve to contain system pressure. Pressure boundaries other than metal, such as composites, are specifically not covered by this document.

1.2 The functions of AE monitoring are to detect, locate, and characterize AE sources to provide data to evaluate their significance relative to pressure boundary integrity. These sources are those activated during system operation, that is, no special stimulus is applied to produce AE. Other methods of nondestructive testing (NDT) may be used, when the pressure boundary is accessible, to further evaluate or substantiate the significance of detected AE sources.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standards.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 6.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E569 Practice for Acoustic Emission Monitoring of Structures During Controlled Stimulation

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E1316 Terminology for Nondestructive Examinations

E2374 Guide for Acoustic Emission System Performance Verification

2.2 *Aerospace Industries Association:*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

2.3 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.4 *ISO Standard:*

ISO 9712 Non-Destructive Testing: Qualification and Certification of NDT Personnel

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *continuous monitoring*—the process of monitoring a pressure boundary continuously to detect acoustic emission during system operation and also during system shut-down testing such as hydrostatic testing.

3.2.2 *raw data*—data values determined directly from measurement of analog inputs. These could include emission count or emission event count, or both, relative time of signal arrival at different sensors (delta time), signal rise time, peak signal amplitude, RMS signal level, pressure system pressure and temperature, and the like.

3.2.3 *processed data*—data resulting from analysis of raw data. Included would be AE source location coordinates, AE versus time from a given source area, AE signal amplitude versus time, and the like.

4. Summary of Practice

4.1 This practice describes the use of a passive monitoring system to detect, locate, and characterize AE sources, in order to evaluate their significance to the integrity of metal pressure boundaries.

4.2 The practice provides guidelines for selection, qualification, verification, and installation of the AE monitoring system. Qualification of personnel is also addressed.

4.3 The practice provides guidelines for using the AE information to estimate the significance of a detected AE source with respect to continued pressure system operation.

5. Significance and Use

5.1 Acoustic emission examination of a structure requires application of a mechanical or thermal stimulus. In this case, the system operating conditions provide the stimulation. During operation of the pressurized system, AE from active discontinuities such as cracks or from other acoustic sources such as leakage of high-pressure, high-temperature fluids can be detected by an instrumentation system using sensors mounted on the structure. The sensors are acoustically coupled to the surface of the structure by means of a couplant material or pressure on the interface between the sensing device and the structure. This facilitates the transmission of acoustic energy to the sensor. When the sensors are excited by acoustic emission energy, they transform the mechanical excitations into electrical signals. The signals from a detected AE source are electronically conditioned and processed to produce information relative to source location and other parameters needed for AE source characterization and evaluation.

5.2 AE monitoring on a continuous basis is a currently available method for continuous surveillance of a structure to assess its continued integrity. The use of AE monitoring in this context is to identify the existence and location of AE sources. Also, information is provided to facilitate estimating the significance of the detected AE source relative to continued pressure system operation.

5.3 Source location accuracy is influenced by factors that affect elastic wave propagation, by sensor coupling, and by signal processor settings.

5.4 It is possible to measure AE and identify AE source locations of indications that cannot be detected by other NDT methods, due to factors related to methodological, material, or structural characteristics.

5.5 In addition to immediate evaluation of the AE sources, a permanent record of the total data collected (AE plus pressure system parameters measured) provides an archival record which can be re-evaluated.

6. Hazards

6.1 **Warning—**Application of this practice will inherently involve work in an operating plant. This may involve potential exposure to hazardous materials and equipment and, in the case of nuclear power plants, exposure to nuclear radiation. A written safety plan shall be prepared for each monitoring installation which defines requirements to be observed to protect personnel safety, safety of the plant system, and to meet administrative and legal needs. This plan shall be approved by all parties prior to start of work on the plant.

7. Basis of Application

7.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

7.2 *Personnel Qualification*

7.2.1 If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

7.3 *Qualification of Nondestructive Agencies*

7.3.1 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

7.4 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of E543 shall be specified in the contractual agreement.

7.5 *Timing of Examination*—The timing of examination shall be continuous, in accordance with 1.1 unless otherwise specified.

7.6 *Extent of Examination*—The extent of examination shall be that part of the pressure boundary in the coverage range of the mounted acoustic emission sensors, unless otherwise specified.

7.7 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 14 unless otherwise specified. Since acceptance criteria (for example, for reference radiographs) are not specified in this practice, they shall be specified in the contractual agreement.

7.8 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this practice and if required shall be specified in the contractual agreement.

7.9 Routine operation of the acoustic emission system for collection and a cursory review of the data may be performed by a competent plant engineer not necessarily specialized in acoustic emission. However, acoustic emission system operation and data interpretation should be verified by a qualified acoustic emission specialist on approximately six-month intervals or sooner if the system appears to be malfunctioning or the data appear unusual.

8. Monitoring System Functional Requirements and Qualification

8.1 *Functional Requirements:*

8.1.1 The monitoring system must include the functional capabilities shown in Fig. 1 which also shows a suggested sequence of monitoring system functions.

8.1.2 *Signal Detection*—The AE sensor together with the acoustic coupling to the structure must have sensitivity sufficient to detect AE signals while the pressure system is operating. In most cases, this determination must be performed when the pressure system is not operating. AE system response to normal operational noise, which must be considered here, is discussed in 9.1. One method of performing the required evaluation is to use a pencil lead break as a signal source. With the sensor in place and connected to the system, the response at the amplifier output to fracturing a 0.3-mm [0.012 in.] pencil lead against the surface being monitored, at a distance of 150 to 300 mm [6 to 12 in.] from the sensor should show a minimum signal-to-noise (electronic plus process noise) ratio of 4 to 1 in the frequency range suitable for the planned monitoring environment. A differential sensor should be considered to minimize interference from electronic transients. The sensor must be capable of withstanding the monitoring environment (temperature, moisture, nuclear radiation, mechanical vibration, and the like) for an extended period of continuous exposure. The minimum length of this period will be dictated by accessibility to the location to change sensors, and by economic considerations.

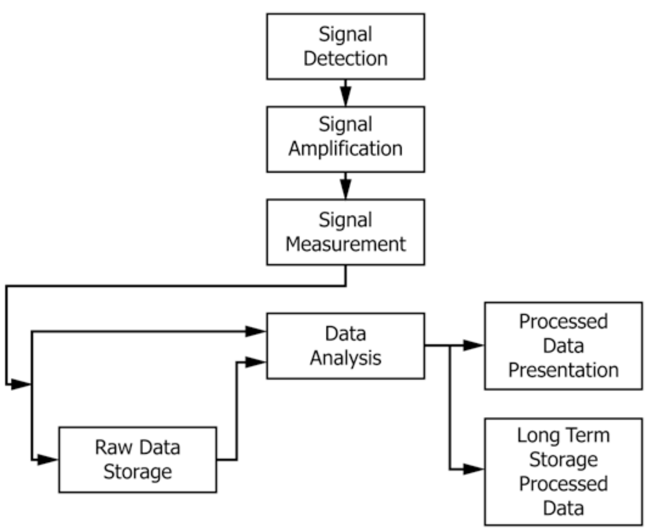

FIG. 1 Functional Flow Diagram—Continuous AE Monitoring System

8.1.3 *Signal Amplification*—For those AE systems that use gain adjustments, appropriate signal amplification in the range of 0 to 60 dB is usually required to achieve an adequate AE signal level for measurement of signal parameters in digital AE systems. Due to the very small magnitude of energy involved in an AE source, it is desirable to locate the signal amplification as near as possible to the output of the sensor. This is beneficial in controlling noise interference and AE signal transmission loss. These preamplifiers must have low inherent electronic background noise. Resistance of the amplifier circuits to the environment (temperature, moisture, nuclear radiation, mechanical vibration, and the like) must be considered and appropriate steps taken to protect them.

NOTE 1—When used herein, peak means zero to peak voltage.

8.1.4 *Monitoring Frequency Band*—The frequency response of the sensor or amplifier combination must be selected for the given application. The AE signal being a transient pulse is detectable over a broad range of frequencies. Because the acoustic attenuation in engineering materials is frequency dependent, it is desirable to use a low monitoring frequency (50 to 100 kHz) to maximize the distance from the AE source over which the AE event can be detected. The low end of the monitoring frequency will usually be controlled by the background noise present in the monitoring environment. In some applications such as operating nuclear reactors, the background noise may require a low frequency cut-off point of 400 to 500 kHz. In cases of severe continuous background noise, inductive tuning of the sensor at the preamplifier input may be effective. The high end of the frequency response band may be limited to 1.0 MHz to help reduce amplifier electronic noise.

8.1.5 *Signal Measurement:*

8.1.5.1 The signal measurement section will receive the fully-amplified analog signal. Generally its operation will be controlled by a voltage threshold circuit which will limit accepted data to that exceeding the voltage amplitude threshold. AE parameters measured may include AE count, AE event count, signal amplitude, time from threshold crossing to signal peak, signal duration, difference in time of signal arrival at various sensors making up a source location array, clock time, data, and the value of any process system parameters (temperature, pressure, strain, and the like) available to the AE monitoring system. If the AE monitoring system is to perform detection of pressure system leaks, it must measure the average signal level or AE rms voltage for each sensing channel.

8.1.5.2 It is desirable that the signal measurements include a function to assess the characteristics of an acoustic emission signal to determine if it matches those originating from crack growth. The function should provide a "flag" for those signals which have characteristics similar to those known to originate from crack growth as determined by an AE specialist.

8.1.5.3 The output from the signal measurement subsystem should be in digital form to facilitate storage of large quantities of data.

8.1.6 *Raw Data Storage*—The AE monitoring system must include a raw digital data storage feature to facilitate retention of the output from the signal measurement subsystem. This serves as a backup in the event that the data analysis process malfunctions, for example, incorrect operation of the data analyzer or loss of power which might destroy data in a computer memory. The raw data storage device must be compact with a high capacity and be nonvolatile. The data retention period will be governed by the operating characteristics of the pressure system and by plant procedures. The storage device should include provision to play back the recorded information directly to the data analysis subsystem or to a peripheral computer.

8.1.7 *Data Analysis:*

8.1.7.1 One of the major functions of the data analysis section is to determine the source of AE signals. There are two primary methods used to locate discrete AE signals:

(a) Calculate the source point using the difference in time of signal arrival at the sensors (Δt) in a given source location array.

(b) Utilize the Δt information to enter a "look-up" table which will define an area including the specific Δt location. Either approach is acceptable. The "look-up" table area resolution must be examined in light of the accuracy requirements of the application. Neither approach can be expected to yield location accuracies closer than ± one wall thickness of the pressure system component being monitored.

8.1.7.2 A third method used largely for processing "continuous" signals produced by a pressure system leak to approximate the source of AE is to compare the amplitude of response from various sensors. This will permit estimating a signal attenuation pattern which will, in turn, indicate the approximate source location.

8.1.7.3 Generally, information in addition to source location will be required. Another function of data analysis is to provide a display, or plot, or both of selected AE information (AE rate, AE from a given source area, AE energy, etc.) versus time, pressure system strain, temperature, etc. for the purpose of correlation evaluations.

8.1.7.4 If the AE monitoring system is to perform pressure system leak detection, a function of data analysis is to provide a continuous assessment of the AE rms signal level. This information can indicate the presence of pressure boundary leakage.

8.1.8 *Processed Data Presentation:*

8.1.8.1 The monitoring system must provide a means of presenting analyzed data on demand. This may take the form of a computer printout alone or a printout in conjunction with a video display. The operator should have the option of specifying the time period of the displayed information.

8.1.8.2 AE rms signal level information must be presented if the AE monitoring system is to perform pressure system leak detection. When the AE rms value exceeds a predetermined level, an operator alert should be activated which will also indicate the sensor producing the high rms value.

8.1.9 *Long Term Storage of Processed Data*—Orderly storage of processed or analyzed data is a key element in the sequence of continuous AE monitoring to assure pressure system integrity. The volume of information to be stored will be inherently large. Digital mass storage plus selected printouts or plots of analyzed information is a suggested approach. The time period for storage will be influenced by two considerations: (1) legal requirements for maintaining records, and (2) the need for engineering analysis data base information.

8.2 *General System Requirements:*

8.2.1 Data processing rate of the total monitoring system is a very important consideration. This will vary with the purpose of the pressure system surveillance. If the objective is solely to indicate impending failure, data rate requirements for processing discrete signals may exceed 100/second for periods of several minutes or more. If the objective is to identify and evaluate crack growth in the early stages, sustained data rate requirements for processing discrete signals may be less than 10/second.

8.2.2 Another general consideration of importance is the capability of the monitoring system to operate continuously over long time periods (one year or greater). Components need to be well suited to such long sustained operation without frequent attention.

9. Monitoring System Performance Verification and Functional Tests

9.1 Various measurements of the acoustic emission monitoring system shall be performed before and after installation on the pressure system to ensure adequate performance. These measurements are described in Practices E750 and E2374. In addition, the following must be evaluated:

9.1.1 *System Response to Process Background Noise*—It is critical that the process background noise be characterized in terms of acoustic emission monitoring system response to the noise excitation. This will be the primary factor in determining acoustic emission system frequency response limitations necessary to avoid noise-masking acoustic emission signals. As a guideline, acoustic emission system response to continuous process background noise should not exceed 35 dBae.

9.1.2 *Prior to Installation*—The operating characteristics of the acoustic emission monitoring system shall be evaluated prior to installation on the pressure system. The evaluation shall specifically include:

9.1.2.1 Frequency response characteristics of each data channel including the sensor and all associated amplifiers to determine if the frequency response is suitable for the intended use. Gas jet excitation of the sensor as defined in Guide E976 is suitable for this. See also 9.1.3.1 of this document.

9.1.2.2 Determine if the dynamic range is large enough to accommodate the planned analysis method. Determine if the system saturates first in the preamplifier(s) or amplifier and if it recovers rapidly.

9.1.2.3 Determine the rate at which the AE monitoring system can acquire and record raw data and to acquire and process data from *one sensor array* for a continuous input over a 1-h period. The rate should be no less than 10 AE events per second. Also, the data rate capability for short intermittent periods of 30 seconds should be at least 100 AE events per second.

9.1.2.4 Determine the accuracy of AE parameter measurements (rise time, amplitude, and the like) of the AE monitoring system using a known signal input.

9.1.3 *After Installation*—The following measurements should be performed after the acoustic emission monitoring system is installed on the pressure boundaries to be monitored. All results should be documented and incorporated in a report on the functional capability of the installed acoustic emission monitoring system. These data are of special importance because they form a baseline reference for acoustic emission system performance. The following measurements should be performed:

9.1.3.1 The AE system response sensitivity versus frequency for each data channel should be measured. This can be accomplished using a helium jet excitation applied from a 210 kPa [30 psi] gage pressure source through a #18 hypodermic needle and impinged on the structure surface at a 3-mm [0.12-in.] standoff distance, 40 mm [1.5 in.] from the mounted sensor. In the case of metal waveguide sensors in particular, care must be exercised to shield the waveguide from impingement of the gas on the waveguide either directly or indirectly. Using the helium jet excitation as described, the peak response at the desired monitoring frequency should be at least 80 dBae (1.0 mV peak output from the sensor). Any data channel showing less than an equivalent of 75 dBae (approximately 0.6 mV peak output) from the sensor should be investigated and the sensor remounted or replaced as necessary to improve sensitivity.

9.1.3.2 Source location accuracy for each sensor array shall be measured using simulated acoustic emission signals injected on the structure surface at known points. At least 10 different points dispersed within each sensor array shall be examined. The location where signals are being injected shall be surrounded with a material such as duct putty to damp out energy propagation by surface wave directly from the signal source. This is particularly important in structures where the energy must cross one or more welds to reach the sensors. Lower attenuation of surface waves by the weld compared to that for longitudinal or shear waves, or both may produce misleading results. Location accuracy should be within a maximum of two wall thicknesses of the structure or 5 % of the sensor spacing distance from the actual point of signal injection, whichever is greater. A suggested method of simulating acoustic emission signals is by use of pencil lead breaks as described in Guide E976.

9.1.3.3 A source of simulated acoustic emission signals should be provided to test the response of the AE monitoring system during pressure system operation. In those cases where access to the sensor locations is impossible during pressure system operation, a remotely controlled source(s) of simulated acoustic emission signals capable of exciting all sensors should be installed on the structure as a permanent part of the installation. This will provide a means of periodically checking the acoustic emission sensors for relative change in sensitivity during the monitoring period. Response of the acoustic emission system to this signal source should be documented as part of the acoustic emission monitoring information. One versatile signal source which can be utilized is an ultrasonic transducer capable of withstanding the pressure system temperature. This has the advantage of being effective over a wide frequency range. Another possible source is a mechanical impactor. However, this device has limited effectiveness at frequencies above approximately 250 kHz. Refer to Guide E2374 for more information on AE system verification.

10. Monitoring System Installation

10.1 Special requirements for installation of acoustic emission monitoring system components imposed by pressure system requirements must be considered and an examination plan prepared and approved in advance of the installation. Some of the major considerations are:

10.1.1 *Sensor mounting*—Guide E650 provides general guidance in this area. The use of drilled and tapped holes in the pressure boundary surface is generally not acceptable. Use of any bonding or acoustic coupling agent, or both shall be supported by chemical analysis of the material to assure that it does not contain elements harmful to the pressure boundary material. Pressure coupling the sensors to the structure surface through the use of magnetic mounts or fixtures secured in place by steel bands are generally acceptable methods. The sensor should be electrically isolated from the structure to minimize electrical interference.

10.1.2 Penetration of protective barriers with signal leads must be approached with care to avoid compromising the protection barrier and to avoid incurring noise or loss of AE signal, or both.

10.1.3 *Signal lead routing inside of protective barriers*—in the case of nuclear plants, signal leads will generally need to be routed through metal conduit.

10.1.4 *Seismic qualification*—in nuclear plants, all components will have to be evaluated for safety from a seismic stand-point.

10.2 This is not intended to be an all inclusive list of considerations. It is the responsibility of those applying this practice to independently evaluate each installation.

11. Procedure

11.1 Procedural guidelines for continuous monitoring are limited because it is a passive function which will not control operation of the pressure system. It is, thus, very important that a written procedure be prepared for each installation to recognize unique requirements. Items to be addressed in the procedure are discussed in this section.

11.1.1 *Pressure System Startup*—Pressure system startup may be the most critical period of an operating cycle for flaw growth due to a combination of pressure stresses and thermal stresses. During this period, acoustic emission count and source location information shall be closely observed for any indication of flaw growth. The rms signal level shall also be observed for indications of leaks in the pressure system.

11.1.2 *Normal Pressure System Operation:*

11.1.2.1 Analysis and summary of acoustic emission data on a weekly basis is suggested during normal plant operation. Acoustic emission count and source location should be examined for trends or build up or both of data at a given location.

11.1.2.2 Response of the acoustic emission system to the installed acoustic signal source (see 9.1.3.3) shall be evaluated on a monthly basis. Indication of deterioration of sensitivity of any sensor must be noted and the sensor(s) shall be replaced at the earliest opportunity.

12. Interpretation of Monitoring Results

12.1 Criteria for interpretation of acoustic emission information from continuous monitoring of a pressure boundary during pressure system operation are both qualitative and quantitative.

12.1.1 The first indication of a significant condition will be a consistent clustering of data source locations within an area approximately 3 times the wall thickness or 10 % of the sensor spacing distance in surface dimensions, whichever is greater. When this condition occurs, thorough analysis must be initiated. The condition should first be evaluated in light of other available plant operating information to determine if the source can be definitely associated with an innocuous cause. If this is not the case, the condition must be considered as a growing flaw.

12.1.2 Given an indication of a growing flaw, the data should be filtered to obtain a measure of acoustic emission events versus time for the localized area of the data source location cluster. If this is a linear curve, it indicates that the flaw is growing in a stable manner and is not yet a serious condition but requires careful surveillance. If the acoustic emission events versus time becomes an exponentially increasing curve, it indicates that the flaw growth rate is rapidly increasing and represents a serious condition. Also, the data should be analyzed relative to plant operating parameters such as temperature, pressure, and the like. This may provide information on the driving force which will aide in assessing significance.

12.1.3 For those acoustic emission monitoring systems which have the analytical capability to assess if a detected signal originates from crack growth, changes in crack growth rate can be estimated with useful accuracy from acoustic emission event rate. An assessment of change in crack growth rate with time by this technique can provide an indication of crack significance.

12.1.4 In cases where it is feasible during pressure system operation or in all cases during pressure system shutdown, acoustic emission indications should be examined with other nondestructive examination methods to provide added definition of AE source significance.

12.1.5 Interpretation of acoustic emission data obtained during hydrostatic testing of the pressure system should be in accordance with Practice E569.

12.1.6 A sudden, sustained increase in the AE rms signal level from the sensors in one or more sensor arrays is indicative of a leak in the pressure system. In this case, the AE rms signal level from all sensors should be examined to determine the relative level of response to the leak. This will provide an indication of the location of the leak.

13. Data Record Requirements

13.1 The safety and examination plan documents shall be retained as permanent records.

13.2 Installed acoustic emission system characterization and calibration results shall be retained on record until such time that the acoustic emission system is recalibrated.

13.3 Raw data records shall be retained until acoustic emission indications can be independently verified as a minimum.

13.4 Retention period for processed data records shall be determined by the pressure system owner or operator.

14. Administrative Record Requirements

14.1 A summary of acoustic emission monitoring results shall be prepared at the end of each pressure system operating cycle. This should be a brief, concise report suitable for management review.

14.2 Reporting requirements in the event of unusual acoustic emission indications shall be defined by the pressure system owner or operator.

15. Keywords

15.1 acoustic emission; acoustic emission source location; continuous monitoring; leak detection; metal piping; metal pressure vessels; pressure systems

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STANDARD PRACTICE FOR LEAK DETECTION AND LOCATION USING SURFACE-MOUNTED ACOUSTIC EMISSION SENSORS

(**19**) **SE-1211/SE-1211M**

(Identical with ASTM Specification E1211/E1211M-17.)

Standard Practice for Leak Detection and Location Using Surface-Mounted Acoustic Emission Sensors

1. Scope

1.1 This practice describes a passive method for detecting and locating the steady state source of gas and liquid leaking out of a pressurized system. The method employs surface-mounted acoustic emission sensors (for non-contact sensors see Test Method E1002), or sensors attached to the system via acoustic waveguides (for additional information, see Terminology E1316), and may be used for continuous in-service monitoring and hydrotest monitoring of piping and pressure vessel systems. High sensitivities may be achieved, although the values obtainable depend on sensor spacing, background noise level, system pressure, and type of leak.

1.2 *Units*—The values stated in either SI units or inch-pound units are to be regarded as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standards.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E1002 Practice for Leaks Using Ultrasonics

E1316 Terminology for Nondestructive Examinations

E2374 Guide for Acoustic Emission System Performance Verification

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *AIA Document:*

NAS 410 Certification and Qualification of Nondestructive Testing Personnel

2.4 *ISO Standard:*

ISO 9712 Non-Destructive Testing: Qualification and Certification of NDT Personnel

3. Summary of Practice

3.1 This practice requires the use of contact sensors, amplifier electronics, and equipment to measure their output signal levels. The sensors may be mounted before or during the examination period and are normally left in place once mounted rather than being moved from point to point.

3.2 Detection of a steady-state leak is based on detection of the continuous, broadband signal generated by the leak flow. Signal detection is accomplished through measurement of some input signal level, such as its root-mean-square (RMS) amplitude or average signal level.

3.3 The simplest leak test procedure involves *only* detection of leaks, treating each sensor channel individually. A more complex examination requires processing the signal levels from two or more sensors together to allow computation of the approximate leak location, based on the principle that the leak signal amplitude decreases as a function of distance from the source.

4. Significance and Use

4.1 Leakage of gas or liquid from a pressurized system, whether through a crack, orifice, seal break, or other opening, may involve turbulent or cavitational flow, which generates acoustic energy in both the external atmosphere and the system pressure boundary. Acoustic energy transmitted through the pressure boundary can be detected at a distance by using a suitable acoustic emission sensor.

4.2 With proper selection of frequency passband, sensitivity to leak signals can be maximized by eliminating background noise. At low frequencies, generally below 100 kHz, it is possible for a leak to excite mechanical resonances within the structure that may enhance the acoustic signals used to detect leakage.

4.3 This practice is not intended to provide a quantitative measure of leak rates.

5. Basis of Application

5.1 The following items are subject to contractual agreement between parties using or referencing this practice.

5.2 *Personnel Qualification*

5.2.1 If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS 410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

5.4 *Timing of Examination*—The timing of examination shall be in accordance with 7.1.7 unless otherwise specified.

5.5 *Extent of Examination*—The extent of examination shall be in accordance with 7.1.4 and 10.1.1.1 unless otherwise specified.

5.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with 10.2.2 and Section 11 unless otherwise specified. Since acceptance criteria are not specified in this practice, they shall be specified in the contractual agreement.

5.7 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this practice and if required shall be specified in the contractual agreement.

6. Interferences

6.1 External or internal noise sources can affect the sensitivity of an acoustic emission leak detection system. Examples of interfering noise sources are:

6.1.1 Turbulent flow or cavitation of the internal fluid,

6.1.2 Noise from grinding or machining on the system,

6.1.3 Airborne acoustic noise, in the frequency range of the measuring system,

6.1.4 Metal impacts against, or loose parts frequently striking the pressure boundary, and

6.1.5 Electrical noise pick-up by the sensor channels.

6.2 Stability or constancy of background noise can also affect the maximum allowable sensitivity, since fluctuation in background noise determines the smallest change in level that can be detected.

6.3 The acoustic emission sensors must have stable characteristics over time and as a function of both the monitoring structure and the instrumentation system examination parameters, such as temperature.

6.4 Improper sensor mounting, electronic signal conditioner noise, or improper amplifier gain levels can decrease sensitivity.

7. Basic Information

7.1 The following items must be considered in preparation and planning for monitoring:

7.1.1 Known existing leaks and their distance from the areas to be monitored should be noted so that their influence on the capabilities of the method can be evaluated.

7.1.2 Type of vessel, pipeline, or installation to be examined, together with assembly, or layout drawings, or both, giving sufficient detail to establish dimensions, changes of shape likely to affect flow characteristics, positions of welds, and the location of components such as valves or flanges, and attachments to the vessel or pipe such as pipe hangers where leaks are most likely to arise. Regions with restricted accessibility due to walls, the existence or location of cladding, insulation, or below surface components must be specified.

7.1.3 When location of the peak is of primary interest, quantitative information regarding the leakage rates of interest and whenever possible the type of leak is necessary.

7.1.4 Extent of monitoring, for example, entire volume of pressure boundary, weld areas only, etc.

7.1.5 Material specifications and type of surface covering (for example paint or other coating) to allow the acoustic propagation characteristics of the structure to be evaluated.

7.1.6 Proposed program of pressure application or process-pressure schedule, specifying the pressurization schedule together with a layout or sketch of the pressure-application system and specifying the type of fluid used during the examination, for example, gas, water, or oil.

7.1.7 Time of monitoring, that is, the point(s) in the manufacturing process, or service life at which the system will be monitored, or both.

7.1.8 Frequency range to be used in the monitoring equipment.

7.1.9 Environmental conditions during examination that may affect instrumentation and interpretation of results; for example, temperature, moisture, radioactivity, vibration, pressure, and electromagnetic interference.

7.1.10 Limitations or restrictions on the sensor mounting procedure, if applicable, including restrictions on couplant materials.

7.1.11 The location of sensors or waveguides and preparation for their installation to provide adequate coverage of the areas specified in 7.1.3. Where particular sections are to be examined with particular sensors, the coverage of the vessel or system by sensor subgroups shall be specified. The sensor locations must be given as soon as possible, to allow positioning difficulties to be identified.

7.1.12 The communications procedure between the acoustic emission staff and the control staff, the time intervals at which pressure readings are to be taken, and the procedure for giving warning of unexpected variations in the pressure system.

7.1.13 Requirements for permanent records, if applicable.

7.1.14 Content and format of examination report, if required.

7.1.15 Acoustic Emission Examiner qualifications and certification, if required.

8. Apparatus

8.1 *Sensors*—The acoustic emission sensors are generally piezoelectric devices and should be mounted in accordance with Practice E650 to ensure proper signal coupling. The frequency range of the sensors may be as high as 1 MHz, and either wideband or resonant sensors may be employed. The higher frequencies can be used to achieve greater discrimination against airborne or mechanical background noise.

8.2 *Amplifiers*—Amplifiers/preamplifiers should have sufficient gain or dynamic range, or both, to allow the signal processing equipment to detect the level of acoustic background noise on the pressurized system. The sensor/amplifier bandwidth should be selected to minimize background noise.

8.3 *Signal Processor*—The signal processor measures the RMS level, the acoustic emission signal power, the average signal level, or any other similar parameters of the continuous signal. A leak location processor to compute the source location from signal levels and attenuation data may be included. Alarm setpoints may also be included as a processor function.

8.4 *Leak Signal Simulator:*

8.4.1 A device for simulating leaks should be included to evaluate the effectiveness of the monitoring system. The following could be considered: a sensor on the pressure boundary driven from a random-noise generator, a small water jet, or a gas jet.

8.4.2 When leak location processing is to be performed, leak simulation should be carried out initially over a sufficiently large number of diverse points to verify proper operation of the location algorithm.

9. System Performance Verification

9.1 System performance verification consists of two stages. The first stage concerns periodic calibration and verification of the equipment under laboratory conditions. This procedure is beyond the scope of this practice (see Practice E750) but the results must be made available to the system owners if requested. The second stage concerns in-situ verification to check the sensitivities of all channels and the satisfactory operation of the detection equipment. For every verification operation, a written procedure shall be prepared.

9.2 In-situ sensitivity check of all sensors should be performed by placing a leak signal simulator (see Guide E976) at a specified distance from each sensor and recording the resulting output level from the amplifier, as referred to the amplifier input terminal. Amplifier gains may also be adjusted as appropriate to correct for sensitivity variations.

9.3 Periodic system verification checks shall be made prior to the examination and during long examinations (days) or if any environmental changes occur. The relative verification check is accomplished by driving various sensors or activating various leak simulation devices such as water or gas jets (see Guide E2374) and measuring the outputs of the receiving sensors. The ratio of the outputs of two receiving sensors for a given injection point should remain constant over time. Any change in the ratio indicates a deviation in performance. In this way, all sensors on a system may be compared to one or several reference signals and proper adjustments made (see Guide E976).

9.4 When leak location calculations are to be performed, the acoustic attenuation between sensors should be characterized over the frequency band of interest, especially if the presence of discontinuities, such as pipe joints, may be suspected to affect the uniformity of attenuation. The measurements should then be factored into the source location algorithm.

10. Procedure

10.1 *Pre-Examination Requirements:*

10.1.1 Before beginning the acoustic emission monitoring, ensure that the following requirements are met:

10.1.1.1 Evaluate attenuation effects, that is, the change in signal amplitude with sound-propagation distance, so as to define the effective area covered by each individual sensor; and in the case of sensor sub-groups, the maximum distance between sensing points.

10.1.1.2 Ensure that sensors are placed at the predetermined positions. If it is necessary to modify these positions during installation, record the new sensor locations. Record the method of attachment of the sensors and the couplant used.

10.1.1.3 Review the operating schedule to identify all potential sources of extraneous acoustic noise such as nozzle-plug movement, pump vibration, valve stroking, personnel movement, fluid flow, and turbulence. Such sources may require acoustic isolation or control so that they will not mask relevant leak emission within the vessel or structure being examined. Uncontrolled generation of acoustic interference by conditions such as rain, sleet, hail, sand, wind (for unprotected vessels), chipping, or grinding, shall be evaluated and its effect minimized by acoustic isolation insofar as is practical. A record shall be made of such sources.

10.2 *Acoustic Emission Monitoring:*

10.2.1 The noise level of each channel or each group shall be continuously or periodically recorded, as required. Pressure or other significant parameters, or both, will normally be recorded to allow correlation with the acoustic emission data response.

10.2.2 When an increase in noise level attributable to a leak has been detected, the examiner shall inform the system owner who will then look for the origin of the leak and its nature. If the leak is found to be outside the area of interest on the structure being monitored (extraneous leak) it must be stopped or reduced to a level necessary to ensure satisfactory monitoring. If extraneous leaks cannot be stopped, then the effect of such signals on the acoustic emission system sensitivity shall be noted. A report shall be prepared following the visual (or other) examination for leaks.

11. Report

11.1 Report the following information:

11.1.1 Date of examination,

11.1.2 Identity of examining personnel,

11.1.3 Sensor characteristics and locations,

11.1.4 Method of coupling sensors to the structure,

11.1.5 Acoustic emission system and its characteristics,

11.1.6 Operating conditions,

11.1.7 Initial calibration records,

11.1.8 In-situ equipment verification results,

11.1.9 Results of measurements,

11.1.10 Analysis and verification of results,

11.1.11 Results of visual (or other) examination(s),

11.1.12 Presentation of the numbers and locations of leaks detected,

11.1.13 Analysis of background noise measurements,

11.1.14 Estimate of quality of measurement and causes of any reduced sensitivity, and

11.1.15 Conclusions and recommendations.

12. Keywords

12.1 acoustic emission leak detection; continuous monitoring; hydrotest; leak detection; nondestructive testing; piping systems; pressure vessels

APPENDIX

(Nonmandatory Information)

X1. APPLICATIONS EXAMPLES

X1.1 The following examples were selected to illustrate application of acoustic emission leak detection, and are not intended to provide detailed descriptions of the application.

X1.1.1 *Acoustic Emission Leak Detection of a Safety/Relief Valve*—A safety/relief valve having a leaking pilot-disk seat was examined under laboratory conditions in order to determine the correlation of the leak noise with leak rate or second-stage pressure. The leak rate, downstream temperature, and the RMS voltage of the acoustic signal were plotted against the second-stage pressure in Fig. X1.1. The acoustic emission sensor was clamped onto the external housing of the pilot works. The signal was band-pass filtered in the range from 5 to 10 kHz. The downstream temperature was measured by a thermocouple in the vicinity of the "pilot valve discharge line." As the second stage pressure increased from 275 kPa to 1400 [40 to 200 psi], the leak rate increased 59 %, the temperature increased 9 %, and the acoustic emission RMS voltage increased 370 %. Therefore, the sensitivity of the acoustic detection was excellent (see Fig. X1.1).

X1.1.2 *Acoustic Emission Leak Detection from Seawater Ball Valves*—The U.S. Navy Acoustic Valve Leak Detector (AVLD) monitors leak-associated acoustic emission energy in the frequency range of 10 to 100 kHz. This frequency range was chosen because there is significant energy emitted by leaky valves, and energy in this range is rapidly attenuated with increasing distance from the source. Therefore, background noise can be electronically separated from the signal. Fig. X1.2 shows the estimated leak rate versus acoustic emission level for a 100-mm [4-in.] ball valve.

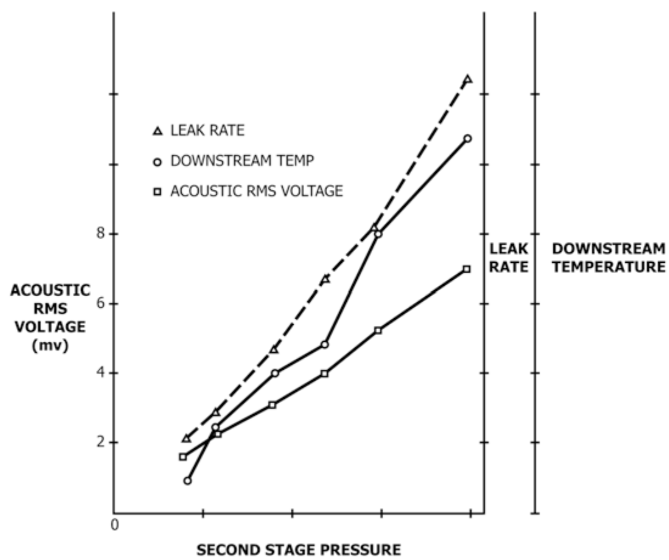

FIG. X1.1 Example of Acoustic Emission Leak Detection in a Safety/Relief Valve of a Nuclear Power Plant

X1.1.3 *Acoustic Emission Leak Detection of a Submerged Crude Oil Transfer Line*—A section of 300-mm [12-in.] diameter steel pipe terminating on an offshore drilling platform was examined for confirmation of a suspected leak. During acceptance hydro testing of the line it was noted that pressure decayed at about 410 kPa/h [60 psi/h] starting at about 22 MPa [3200 psig]. The suspected source of leakage was at the spool piece flanges. Signal level readings were taken on the 400-mm

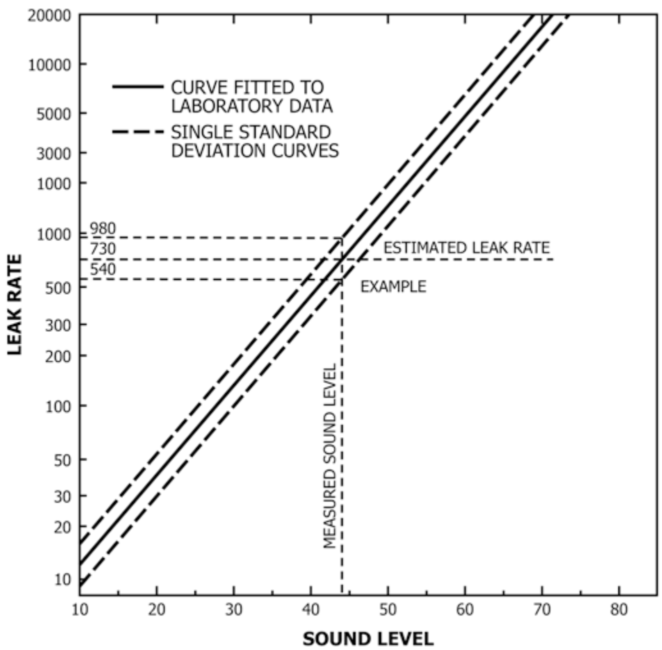

FIG. X1.2 Estimating Leak Rate from Acoustic Emission Level in Seawater Ball Valves

[15.7-in.] riser on the platform after the pressure on the pipe was elevated to 22 MPa [3200 psig]. These signal readings were compared with readings taken on two adjacent pipes, and on the nearest support leg for the structure (see Table X1.1). The additional readings were used to determine the amount of signal that was caused by sea motion and other structural interfering noise. The initial readings were taken with the platform in a shut-down condition and all construction workers onshore. The readings indicated about a 50 % increase in signal level on the leaking pipe as compared to the other two risers and the support leg. This indicated leakage in close proximity to the detection point, in effect, verifying that leakage was in the connecting spool piece flanges. Following tightening by a diver of the identified leaking flange, the acoustic emission examiner determined that the leak had been stopped. No further indications of leakage were detected; either by mechanical means (pressure drop) or by acoustic emission.

TABLE X1.1 Signal Readings

Location	RMS Reading	Comment
150 mm [6 in.] pipe riser	0.200 at 60 dB gain	reference
250 mm [10 in.] pipe riser	0.210 at 60 dB gain	reference
300 mm [12 in.] pipe riser	0.300 at 60 dB gain	leaking pipe
Corner support leg	0.210 at 60 dB gain	reference
Location	RMS Reading	Comment
155 mm [6 in.] pipe riser	0.200 at 60 dB gain	reference
250 mm [10 in.] pipe riser	0.200 at 60 dB gain	reference
300 mm [12 in.] pipe riser	0.200 at 60 dB gain	leak noise is stopped
Corner support leg	0.210 at 60 dB gain	reference

STANDARD PRACTICE FOR EXAMINATION OF SEAMLESS, GAS-FILLED, PRESSURE VESSELS USING ACOUSTIC EMISSION

SE-1419/SE-1419M

(Identical with ASTM Specification E1419/E1419M-15.)

Standard Practice for Examination of Seamless, Gas-Filled, Pressure Vessels Using Acoustic Emission

1. Scope

1.1 This practice provides guidelines for acoustic emission (AE) examinations of seamless pressure vessels (tubes) of the type used for distribution or storage of industrial gases.

1.2 This practice requires pressurization to a level greater than normal use. Pressurization medium may be gas or liquid.

1.3 This practice does not apply to vessels in cryogenic service.

1.4 The AE measurements are used to detect and locate emission sources. Other nondestructive test (NDT) methods must be used to evaluate the significance of AE sources. Procedures for other NDT techniques are beyond the scope of this practice. See Note 1.

NOTE 1—Shear wave, angle beam ultrasonic examination is commonly used to establish circumferential position and dimensions of flaws that produce AE. Time of Flight Diffraction (TOFD), ultrasonic examination is also commonly used for flaw sizing.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E1316 Terminology for Nondestructive Examinations

E2223 Practice for Examination of Seamless, Gas-Filled, Steel Pressure Vessels Using Angle Beam Ultrasonics

E2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod

E2374 Guide for Acoustic Emission System Performance Verification

2.2 *ASNT Standards:*

Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Code of Federal Regulations:*

Section 49, Code of Federal Regulations, Hazardous Materials Regulations of the Department of Transportation, Paragraphs 173.34, 173.301, 178.36, 178.37, and 178.45

2.4 *Compressed Gas Association Standard:*

Pamphlet C-5 Service Life, Seamless High Pressure Cylinders

CGA-C18 Methods for Acoustic Emission Requalification of Seamless Steel Compressed Gas Tubes

2.5 *AIA Document:*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

2.6 *ISO Standards:*

ISO 9712 Non-destructive Testing—Qualification and Certification of NDT Personnel

ISO 16148 Gas Cylinders—Acoustic Emission Testing (AT) for Periodic Inspection

3. Terminology

3.1 *Definitions*—See Terminology E1316 for general terminology applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fracture critical flaw*—a flaw that is large enough to exhibit unstable growth at service conditions.

3.2.2 *marked service pressure*—pressure for which a vessel is rated. Normally this value is stamped on the vessel.

3.2.3 *normal fill pressure*—level to which a vessel is pressurized. This may be greater, or may be less, than *marked service pressure*.

4. Summary of Practice

4.1 The AE sensors are mounted on a vessel, and emission is monitored while the vessel is pressurized above normal fill pressure.

4.2 Sensors are mounted at each end of the vessel and are connected to an acoustic emission signal processor. The signal processor uses measured times of arrival of emission bursts to determine linear location of emission sources. If measured emission exceeds a prescribed level (that is, specific locations produce enough events), then such locations receive secondary NDT (for example, ultrasonic examination).

4.3 Secondary examination establishes presence of flaws and measures flaw dimensions.

4.4 If flaw depth exceeds a prescribed limit (that is, a conservative limit that is based on construction material, wall thickness, fatigue crack growth estimates, and fracture critical flaw depth calculations), then the vessel must be removed from service.

5. Significance and Use

5.1 Because of safety considerations, regulatory agencies (for example, U.S. Department of Transportation) require periodic examinations of vessels used in transportation of industrial gases (see Section 49, Code of Federal Regulations). The AE examination has become accepted as an alternative to the common hydrostatic proof test. In the common hydrostatic test, volumetric expansion of vessels is measured.

5.2 An AE examination should not be performed for a period of one year after a common hydrostatic test. See Note 2.

NOTE 2—The Kaiser effect relates to decreased emission that is expected during a second pressurization. Common hydrostatic tests use a relatively high pressure (167 % of normal service pressure). (See Section 49, Code of Federal Regulations.) If an AE examination is performed too soon after such a pressurization, the AE results will be insensitive to a lower examination pressure (that is, the lower pressure that is associated with an AE examination).

5.3 *Pressurization:*

5.3.1 General practice in the gas industry is to use low pressurization rates. This practice promotes safety and reduces equipment investment. The AE examinations should be performed with pressurization rates that allow vessel deformation to be in equilibrium with the applied load. Typical current practice is to use rates that approximate 3.45 MPa/h [500 psi/h].

5.3.2 Gas compressors heat the pressurizing medium. After pressurization, vessel pressure may decay as gas temperature equilibrates with ambient conditions.

5.3.3 Emission from flaws is caused by flaw growth and secondary sources (for example, crack surface contact and contained mill scale). Secondary sources can produce emission throughout vessel pressurization.

5.3.4 When pressure within a vessel is low, and gas is the pressurizing medium, flow velocities are relatively high. Flowing gas (turbulence) and impact by entrained particles can produce measurable emission. Considering this, acquisition of AE data may commence at some pressure greater than starting pressure (for example, ⅓ of maximum examination pressure).

5.3.5 *Maximum Test Pressure*—Serious flaws usually produce more acoustic emission (that is, more events, events with higher peak amplitude) from secondary sources than from flaw growth. When vessels are pressurized, flaws produce emission at pressures less than normal fill pressure. A maximum examination pressure that is 10 % greater than normal fill pressure allows measurement of emission from secondary sources in flaws and from flaw growth.

5.3.6 *Pressurization Schedule*—Pressurization should proceed at rates that do not produce noise from the pressurizing medium and that allow vessel deformation to be in equilibrium with applied load. Pressure holds are not necessary; however, they may be useful for reasons other than measurement of AE.

5.4 Excess background noise may distort AE data or render them useless. Users must be aware of the following common sources of background noise: high gas-fill rate (measurable flow noise); mechanical contact with the vessel by objects; electromagnetic interference (EMI) and radio frequency interference (RFI) from nearby broadcasting facilities and from other sources; leaks at pipe or hose connections; and airborne sand particles, insects, or rain drops. This practice should not be used if background noise cannot be eliminated or controlled.

5.5 Alternate procedures are found in ISO 16148 and CGA C18. These include hydrostatic proof pressurization of individual vessels and data interpretation using modal analysis techniques

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.4 *Time of Examination*—The timing of examination shall be in accordance with 5.2 unless otherwise specified.

6.5 *Extent of Examination*—The extent of examination includes the entire pressure vessel unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 11 unless otherwise specified. Since acceptance criteria (for example, reference radiographs) are not specified in this practice, they shall be specified in the contractual agreement.

6.7 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this practice and if required shall be specified in the contractual agreement.

7. Apparatus

7.1 Essential features of the apparatus required for this practice are provided in Fig. 1. Full specifications are in Annex A1.

7.2 Couplant must be used to acoustically connect sensors to the vessel surface. Adhesives that have acceptable acoustic properties, and adhesives used in combination with traditional couplants, are acceptable.

7.3 Sensors may be held in place with magnets, adhesive tape, or other mechanical means.

7.4 The AE sensors are used to detect strain-induced stress waves produced by flaws. Sensors must be held in contact with the vessel wall to ensure adequate acoustic coupling.

7.5 A preamplifier may be enclosed in the sensor housing or in a separate enclosure. If a separate preamplifier is used, cable length, between sensor and preamp, must not exceed 2 m [6.6 ft].

7.6 Power/signal cable length (that is, cable between preamp and signal processor) shall not exceed 150 m [500 ft]. See A1.5.

7.7 Signal processors are computerized instruments with independent channels that filter, measure, and convert analog information into digital form for display and permanent storage. A signal processor must have sufficient speed and capacity to independently process data from all sensors simultaneously. The signal processor should provide capability to filter data for replay. A printer should be used to provide hard copies of examination results.

7.7.1 A video monitor should display processed examination data in various formats. Display format may be selected by the equipment operator.

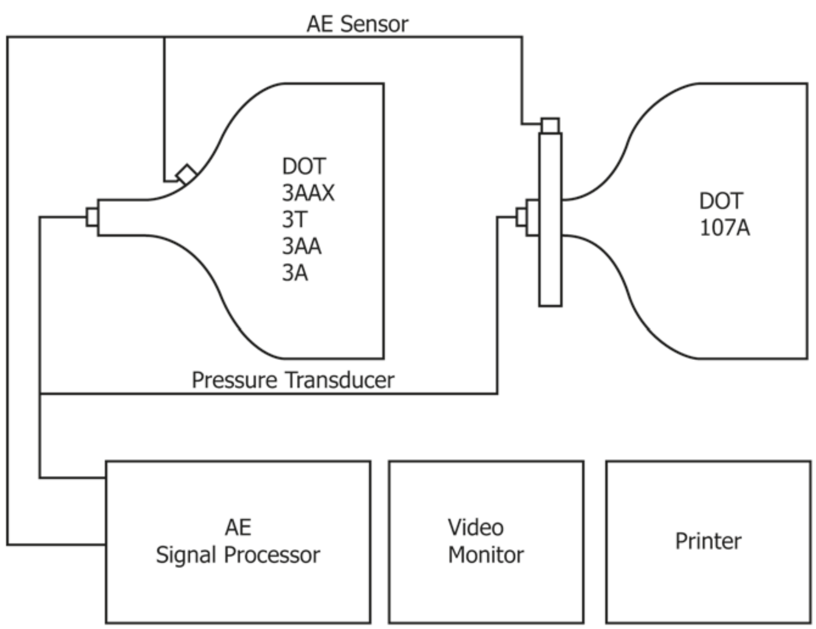

FIG. 1 Essential Features of the Apparatus with Typical Sensor Placements

7.7.2 A data storage device may be used to provide data for replay or for archives.

7.7.3 Hard copy output capability should be available from a printer or equivalent device.

8. Safety Precautions

8.1 As in any pressurization of metal vessels, ambient temperature should not be below the ductile-brittle transition temperature of the pressure vessel construction material.

9. Calibration and Standardization

9.1 Annual calibration and verification of pressure transducer, AE sensors, preamplifiers (if applicable), signal processor (particularly the signal processor time reference), and AE electronic waveform generator should be performed. Equipment should be adjusted so that it conforms to equipment manufacturer's specifications. Instruments used for calibrations must have current accuracy certification that is traceable to the National Institute for Standards and Technology (NIST).

9.2 Routine electronic evaluation of the signal processor should be performed monthly and any time there is concern about signal processor performance. An AE electronic waveform generator should be used in making evaluations. Each signal processor channel must respond with peak amplitude reading within ±2 dBV of the electronic waveform generator output.

9.3 Routine evaluation of the sensors should be performed monthly. An accepted procedure for this purpose found in Practice E2075 and Guide E976.

9.4 Routine verification of the system's ability to locate and cluster data should be performed monthly. With two sensors mounted on one tube and a ruler taped to the tube surface, use a pencil lead break (PLB) at 60 cm [2 ft.] intervals along the entire length of the tube (5 PLBs at each point). Examine the recorded data to verify that locations and clusters are in the correct positions.

9.5 Pre-examination and post-examination, system performance verification must be conducted immediately before, and immediately after, each examination. System performance verification uses a mechanical device to induce stress waves into the vessel wall at a specified distance from each sensor. Induced stress waves stimulate a sensor in the same way as emission from a flaw. System performance verification verifies performance of the entire system (including sensors, cables, and couplant). Procedures for system performance verification are found in Guide E2374.

9.5.1 The preferred technique for conducting a system performance verification is a PLB. Lead should be broken on the vessel surface no less than 10 cm [4 in.] from the sensor. The 2H lead, 0.3-mm [0.012-in.] diameter, 3-mm [0.012-in.] long should be used (see Fig. 5 of Guide E976).

9.5.2 *Auto Sensor Test (AST)*—An electromechanical device such as a piezoelectric pulser (and sensor which contains this function) can be used in conjunction with pencil lead break (9.5.1) as a means to assure system performance. If AST is used in conjunction with PLB for pre-examination then AST may be used, solely, for post examination system performance verification.

10. Procedure

10.1 Visually examine accessible exterior surfaces of the vessel. Note observations in examination report.

10.2 Isolate vessel to prevent contact with other vessels, hardware, and so forth. When the vessel cannot be completely isolated, indicate, in the examination report, external sources which could have produced emission.

10.3 Connect fill hose and pressure transducer. Eliminate any leaks at connections.

10.4 Mount an AE sensor at each end of each tube (see Fig. 1 for typical sensor placement). Use procedures specified in Guide E650. Sensors must be at the same angular position and should be located at each end of the vessel so that the AE system can determine axial locations of sources in as much of the vessel as possible.

NOTE 3—AE instrumentation utilizing waveform based analysis techniques may require sensor placement inboard of the tube ends to achieve optimum source location results.

10.5 Adjust signal processor settings. See Appendix X1 for example.

10.6 Perform system performance verification at each sensor (see 9.5). Verify that peak amplitude is greater than a specified value (see Table X1.2). Verify that the AE system displays a correct location (see Note 5) for the mechanical device that is used to produce stress waves (see 9 and Table X1.2). Prior to pressurization, verify that there is no background noise above the signal processor threshold setting.

NOTE 4—Sensors must be mounted as close to the tube end as possible to optimize linear source location accuracy (refer to Fig. 1). Mounting on the tube shoulder, close to the tube neck is acceptable.

NOTE 5—If desired location accuracy cannot be attained with sensors at two axial locations, then more sensors should be added to reduce sensor spacing.

10.7 Begin pressurizing the vessel. The pressurization rate shall be low enough that flow noise is not recorded.

10.8 Monitor the examination by observing displays that show plots of AE events versus axial location. If unusual response (in the operator's judgment) is observed, interrupt pressurization and conduct an investigation.

10.9 Store all data on mass storage media. Stop the examination when the pressure reaches 110 % of normal fill pressure or 110 % of marked service pressure (whichever is greater). The pressure shall be monitored with an accuracy of ±2 % of the maximum examination pressure.

10.9.1 *Examples:*

10.9.1.1 A tube trailer is normally filled to a gage pressure of 18.20 MPa [2640 psi]. Pressurization shall stop at 20 MPa [2900 psi].

10.9.1.2 A gas cylinder is normally filled to a gage pressure of 4.23 MPa [613 psi]. The marked service pressure is 16.55 MPa [2400 psi]. Pressurization shall stop at 18.20 MPa [2640 psi].

10.10 Perform a system performance verification at each sensor (see 9.5). Verify that peak amplitude is greater than a specified value (see Table X1.2).

10.11 Reduce pressure in vessel to normal fill pressure by bleeding excess gas to a receiver, or vent the vessel.

10.12 Raw AE data should be filtered to eliminate emission from nonstructural sources, for example, electronic noise.

10.13 Replay examination data. Examine the location distribution plots (AE events versus axial location) for all vessels in the examination.

10.14 All locations on a pressure vessel (e.g. DOT 3AAX tube) with five or more located AE events that occurred within a 20.3 cm [8 in.] axial distance, on the cylindrical portion of a tube, must have a follow-up inspection using Practice E2223. Appendix X1 provides examples of such determinations.

11. Report

11.1 Prepare a written report from each examination. Report the following information:

11.1.1 Name of the owner of the vessel and the vehicle number (if appropriate).

11.1.2 Examination date and location.

11.1.3 Previous examination date and previous maximum pressurization. See Note 6.

NOTE 6—If the operator is aware of situations where the vessel was subject to pressures that exceeded normal fill pressure, these should be described in the report.

11.1.4 Any U.S. Department of Transportation (DOT) specification that applies to the vessel.

11.1.5 Any DOT exemption numbers that apply to the vessel.

11.1.6 Normal fill pressure and marked service pressure.

11.1.7 Pressurization medium.

11.1.8 Amplitude measurements from pre- and post-performance verification.

11.1.9 Pressure at which data acquisition commenced.

11.1.10 Maximum examination pressure.

11.1.11 Record wave velocity and threshold used in the location calculation.

11.1.12 Locations of AE sources that exceed acceptance criteria. Location shall include distance from end of vessel that bears the serial number (usually this is stamped in the vessel wall).

11.1.13 Signature of examiner.

11.1.14 Stacking chart that shows relative locations of vessels (if a multiple vessel array is tested).

11.1.15 Visual examination results.

11.1.16 AE examination results, including events versus location plots for each vessel and cumulative events versus pressure plot for each vessel.

12. Keywords

12.1 acoustic emission; flaws in steel vessels; gas pressure vessels; seamless gas cylinders; seamless steel cylinders; seamless vessels

ANNEX

(Mandatory Information)

A1. INSTRUMENTATION SPECIFICATIONS

A1.1 Sensors

A1.1.1 The AE sensors shall have high sensitivity within the frequency bandpass of intended use. Sensors may be broad band or resonant.

A1.1.2 Sensitivity shall be greater than 70 dBV from a PLB source (as described in subsection 4.3.3 of Guide E976).

A1.1.3 Sensitivity within the range of intended use shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

A1.1.4 Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design, or both.

A1.1.5 Sensors shall be electrically isolated from conductive surfaces by means of a shoe (a wear plate).

A1.2 Signal Cable

A1.2.1 The sensor signal cable which connects sensor and preamplifier shall not reduce sensor output more than 3 dB (2 m [6.6 ft] is a typical maximum length). Integral preamplifier sensors meet this requirement. They have inherently short, internal, signal cables.

A1.2.2 Signal cable shall be shielded against electromagnetic interference. Standard coaxial cable is generally adequate.

A1.3 Couplant

A1.3.1 A couplant shall provide adequate ultrasonic coupling efficiency throughout the examination.

A1.3.2 The couplant must be temperature stable over the temperature range intended for use.

A1.3.3 Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

A1.4 Preamplifier

A1.4.1 The preamplifier shall have noise level no greater than 7 µV rms (referred to a shorted input) within the bandpass range.

A1.4.2 The preamplifier gain shall vary no more than ±1 dB within the frequency band and temperature range of use.

A1.4.3 The preamplifier shall be shielded from electromagnetic interference.

A1.4.4 The preamplifiers of differential design shall have a minimum of 40-dB common mode rejection.

A1.5 Power/Signal Cable

A1.5.1 The power/signal cables provide power to preamplifiers, and conduct amplified signals to the main processor. These shall be shielded against electromagnetic interference. Signal loss shall be less than 1 dB/ 30 m [100 ft] of cable length. Standard coaxial cable is generally adequate. Signal loss from a power/signal cable shall be no greater than 3 dB.

A1.6 Power Supply

A1.6.1 A stable, grounded, power supply that meets the signal processor manufacturer's specification shall be used.

A1.7 Signal Processor

A1.7.1 The electronic circuitry gain shall be stable within ±2 dB in the temperature range of 40°C [100°F].

A1.7.2 Threshold shall be accurate within ±2 dB.

A1.7.3 Measured AE parameters shall include: threshold crossing counts, peak amplitude, arrival time, rise time, and duration for each hit. Also, vessel internal pressure shall be measured.

A1.7.4 The counter circuit shall count threshold crossings within an accuracy of ±5 % of true counts.

A1.7.5 Peak amplitude shall be accurate within ±2 dBV.

A1.7.6 Duration shall be accurate to within ±10 μs.

A1.7.7 Threshold shall be accurate to within ±1 dB.

A1.7.8 Arrival time shall be accurate to 0.5 μs.

A1.7.9 Rise time shall be accurate to ±10 μs.

A1.7.10 Parametric voltage readings from pressure transducers shall be accurate to within ±5 % of the marked service pressure.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE INSTRUMENT SETTINGS AND REJECTION CRITERIA

X1.1 A database and rejection criteria are established for some DOT specified vessels. These have been described in the NDT Handbook.[1] More recent criteria are described in this section. Some vessel types, typical dimensions, and service pressures are listed in Table X1.1.

X1.2 Criteria for determining the need for secondary examination were established while working with AE equipment with setup conditions listed in Table X1.2.

X1.3 Need for secondary examination is based on location distribution plots (that is, plots of AE events versus axial location) after AE data acquisition is completed.

X1.3.1 *Location Error Due to Hyperbola Error*—The accuracy of linear location techniques used on two dimensional objects such as gas tubes is very good on a straight line between the sensors. However, off axis, linear source location accuracy diminishes significantly for sources near the tube ends. The poorest source location accuracy is 180° from the axis. The reason for the inaccuracy can be explained by investigating the algorithm that forms the basis for linear source location, a series of hyperbolas. The vertex of each hyperbola lies on the axis (hence good accuracy along the

TABLE X1.2 Acoustic Emission Equipment, Characteristics, and Setup Conditions

Sensor sensitivity	>70 dBV using PLB source (see A1.1.2)
Couplant	silicone grease
Preamplifier gain	40 dB (×100)
Preamplifier filter	100 to 300-kHz bandpass
Power/signal cable length	<500 ft (152.4 m)
Signal processor filter	100 to 300-kHz bandpass
Dead time	10 ms
Background noise	<27 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Sensitivity check	>70 dBV (PLB, 0.3 mm [0.012 in.], 3 mm [0.12 in.], 10 cm [4 in.]

TABLE X1.1 Specified Cylinders, Typical Dimensions, and Service Pressures

Specification	DOT 3AAX	DOT 3T	DOT 3A	DOT 3AA	DOT 107A
Outside diameter	56 cm [22 in.]	56 cm [22 in.]	25 cm [9.8 in.]	25 cm [9.8 in.]	46 cm [18 in.]
Nominal wall thickness	1.4 cm [0.55 in.]	1.1 cm [0.43 in.]	0.79 cm [0.31 in.]	0.64 cm [0.25 in.]	1.9 or 2.2 cm [0.75 or 0.86 in.]
Length	5.5 to 12 m [18 to 40 ft]		4 to 10 m [13 to 33 ft]		10 m [33ft]
Typical service pressure	16.6 MPa [2400 psi]				18 or 23 MPa [2600 or 3300 psi]
Typical fill pressure	14.14 to 20.7 [600 to 3000]				18 to 23 MPa [2600 to 3300 psi]
Alternate retest method	hydrostatic test, at 1.67 times marked service pressure every five years with volumetric expansion measurement				

[1] Miller, R. K., and McIntire, P., *Nondestructive Testing Handbook*, 2nd ed., Vol 5, *Acoustic Emission Testing* , American Society for Nondestructive Testing, Columbus, Ohio, 1987 , pp. 161–165.

axis). When the algorithm is used on a plane (two-dimensional) each hyperbola maps out positions on the tube which will be reported as having the same source location. At the exact center between the sensors there is no inaccuracy for positions around the tube. As we move away from the center, the curve of the hyperbolas bends toward the sensor. The hyperbola error is illustrated in Fig. X1.1. Table X1.3 is a compilation of the error (difference between on-axis and 180° off-axis hyperbola coordinates). Data is presented for tubes of different diameters. The error was determined graphically using the equation for a hyperbola to calculate several coordinate points to construct the hyperbola line. The error decreases at the end due to the hemispherical shape.

X1.3.2 Follow-up inspection is necessary at the position of any cluster ±460 mm [±18 in.]. Follow-up inspection involves a secondary NDT method (for example, ultrasonic examination). Any indication that is detected must be precisely located, and flaw dimensions must be determined.

X1.4 *Rejection Criterion:*

X1.4.1 Vessels that contain flaws that are large enough to be "fracture critical flaws," or that contain flaws large enough to grow to fracture critical size before another re-examination is performed, shall be removed from service.

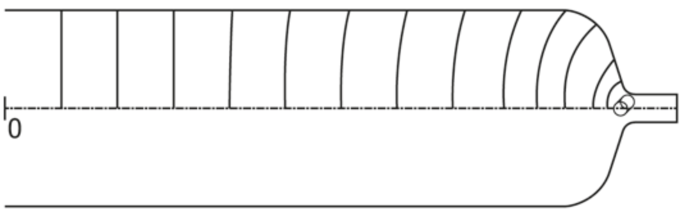

FIG. X1.1 Hyperbolas drawn on a 56 cm [22 in.] diameter tube with 1016 cm [400 in.] sensor spacing. The tube is drawn as a two-dimensional flat surface. The drawing is not to scale.

X1.4.2 "Fracture critical" flaw dimensions are based upon fracture mechanics analysis of a vessel using strength properties that correspond to materials of construction.

X1.4.3 Analyses of DOT 3AAX and 3T tubes are described by Blackburn and Rana.[2] Fracture critical flaw depths were calculated, and fatigue crack growth (under worst case conditions) was estimated. Flaw depths that could grow to half the fracture critical size were judged too large. They should not remain in service. Based upon this conservative approach, DOT Specification 3AAX and 3T tubes with maximum flaw depths of 2.54 mm [0.10 in.], or more, should be permanently removed from service.

X1.4.3.1 The DOT 3AAX and 3T cylinders have been evaluated by Blackburn and Rana.[2] The maximum allowable flaw depth was calculated to be 2.5 mm [0.10 in.].

X1.4.3.2 The DOT 3AA and 3A cylinders were evaluated by Blackburn.[3] Maximum allowable depths were calculated, and 1.5 mm [0.06 in.] was specified for both specifications.

X1.4.3.3 The DOT 107A cylinders have been evaluated by Toughiry.[4] The maximum flaw depth was calculated to be 3.8 mm [0.150 in.].

[2] Blackburn, P. R., and Rana, M. D., "Acoustic Emission Testing and Structural Evaluation of Seamless, Steel, Tubes in Compressed Gas Service," *Transactions of the American Society of Mechanical Engineers, Journal of Pressure Vessel Technology*, Vol 108, May 1986, pp. 234–240.

[3] Docket No. 11099, Application for Exemption, Appendix II," Maximum Allowable Flaw Depth, 3A and 3AA Tubes," U.S. Department of Transportation, Jan. 14, 1988.

[4] Toughiry, M. M., Docket No. 11059, Application for Exemption from the Requirements of *Hazardous Materials Regulations of the DOT* , U.S. Bureau of Mines, Helium Field Operation, June 1993.

TABLE X1.3 Compilation of Error

Distance from Center of Tube	560 mm [22 in.] Diameter Calculated/Actual Error	510 mm [20 in.] Diameter Calculated/Actual Error	460 mm [18 in.] Diameter Calculated/Actual Error	245 mm [9.63 in.] Diameter Calculated/Actual Error
0	0	0	0	0
50 cm [20 in.]	6.3 mm [0.25 in.]	5 mm [0.2 in.]	4.0 mm [0.2 in.]	1.3 mm [0.05 in.]
100 cm [40 in.]	13 mm [0.5 in.]	10.5 mm [0.4 in.]	8.6 mm [0.3 in.]	2.5 mm [0.1 in.]
150 cm [60 in.]	20 mm [0.8 in.]	16.5 mm [0.7 in.]	13.5 mm [0.5 in.]	3.8 mm [0.15 in.]
200 cm [80 in.]	29 mm [1.1 in.]	23.5 mm [0.9 in.]	19 mm [0.8 in.]	5.6 mm [0.22 in.]
250 cm [100 in.]	39 mm [1.5 in.]	32.5 mm [1.3 in.]	26 mm [1.0 in.]	7.6 mm [0.3 in.]
300 cm [120 in.]	53 mm [2.1 in.]	44 mm [1.7 in.]	35.5 mm [1.4 in.]	10 mm [0.4 in.]
350 cm [140 in.]	72.5 mm [2.9 in.]	60 mm [2.4 in.]	48.7 mm [1.9 in.]	14 mm [0.6 in.]
400 cm [16 in.]	105 mm [4.1 in.]	87 mm [3.4 in.]	70 mm [2.8 in.]	20 mm [0.8 in.]
450 cm [180 in.]	167 mm [6.6 in.]	138 mm [5.5 in.]	112 mm [4.4 in.]	32.5 mm [1.3 in.]
500 cm [200 in.]	348 mm [13.7 in.]/ 259 mm [10.2 in.]	290 mm [11.4 in.]/ 250 mm [10.0 in.]	235 mm [9.3 in.]	52.6 mm [2.1 in.]
530 cm [210 in.]	693 mm [27.2 in.]/ 178 mm [7.0 in.]	580 mm [23 in.]/ 178 mm [7.0 in.]	472 mm [18.6 in.]/ 178 mm [7.0 in.]	140 mm [5.5 in.]

STANDARD PRACTICE FOR VERIFYING THE CONSISTENCY OF AE-SENSOR RESPONSE USING AN ACRYLIC ROD

SE-2075/SE-2075M

(Identical with ASTM Specification E2075/E2075M-15.)

Standard Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod

1. Scope

1.1 This practice is used for routinely checking the sensitivity of acoustic emission (AE) sensors. It is intended to provide a reliable, precisely specified way of comparing a set of sensors, or telling whether an individual sensor's sensitivity has degraded during its service life, or both.

1.2 This practice is not a "calibration" nor does it give frequency response information.

1.3 *Units*—The values stated in SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E2374 Guide for Acoustic Emission System Performance Verification

3. Significance and Use

3.1 Degradation in sensor performance can occur due to dropping, mechanical shock while mounted on the test structure, temperature cycles, and so forth. It is necessary and desirable to have a simple measurement procedure that will check the consistency of sensor response, while holding all other variables constant.

3.2 While test blocks of many different kinds have been used for this purpose for many years, an acrylic polymer rod offers the best all-around combination of suitable acoustic properties, practical convenience, ease of procurement and low cost.

3.3 Because the acoustic properties of the acrylic rod are known to depend on temperature, this practice requires that the rod, sensors, and couplant be stabilized at the same working temperature, prior to verifying the sensors.

3.4 Attention should be paid to storage conditions for the acrylic polymer rod. For example, it should not be left in a freezing or hot environment overnight, unless it is given time for temperature stabilization before use.

3.5 Properly applied and with proper record keeping, this practice can be used in many ways. The user organization must determine the context for its use, the acceptance standards and the actions to be taken based on the lead break results. The following uses are suggested:

3.5.1 To determine when a sensor is no longer suitable for use.

3.5.2 To check sensors that have been exposed to high-risk conditions, such as dropping, overheating, and so forth.

3.5.3 To get an early warning of sensor degradation over time. This can lead to identifying conditions of use, which are damaging sensors, and thus, to better equipment care and lower replacement costs.

3.5.4 To obtain matched sets of sensors, preamplifiers, instrumentation channels, or a combination thereof, for more uniform performance of the total system.

3.5.5 To save time and money, by eliminating the installation of bad sensors.

3.5.6 To verify sensors quickly but consistently in the field and to assist trouble-shooting when a channel does not pass a performance check.

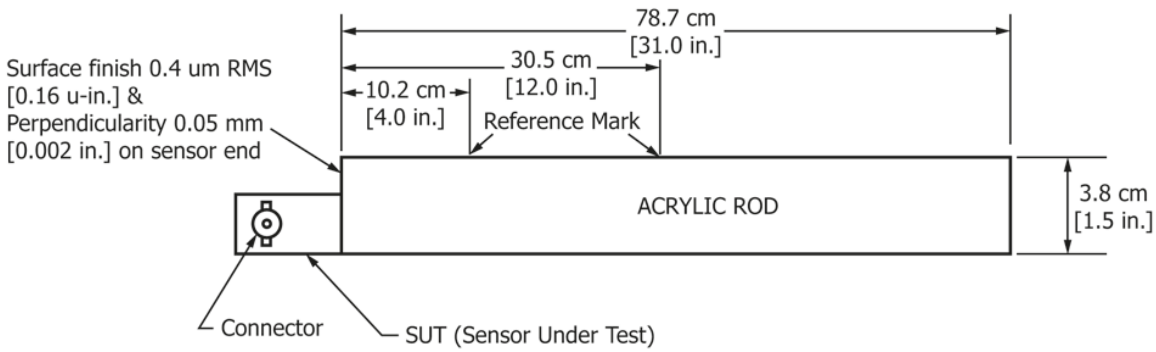

FIG. 1 Acrylic Rod Description

3.6 All the above uses are recommended for consideration. The purpose of this practice is not to call out how these uses are to be implemented, but only to state how the test itself is to be performed so that the results obtained will be accurate and reliable.

4. Apparatus

4.1 *Acrylic Polymer Cylindrical Rod* (Fig. 1), should be used. The actual material of the acrylic polymer rod is polymethylmethacrylate.

4.1.1 The rod shall be cast, not extruded.

4.1.2 Dimensions of the rod should be 78.7 cm [31 in.] long by 3.8 cm [1.5 in.] in diameter, sensors end cut true and smooth with a surface finish of 0.4 µm RMS [0.16 µin.].

4.1.3 Other lengths of rod are acceptable, provided that there is sufficient distance to attenuate and prevent reflected signals from the nonsensor end of the rod reaching the sensor.

4.1.4 A permanent reference mark, for example an “X”, is placed on the rod at a distance of 10.2 cm [4 in.], or 30.5 cm [12 in.], or both, from one end; marking the spots where the pencil lead is to be broken. It is convenient to provide a very small spotface, for example, 0.8 mm [0.03 in.] diameter and 0.1 mm [0.004 in.] deep at these reference mark points, to rest the tip of the pencil lead to avoid slippage during the lead break process.

NOTE 1—The surface finish of the cylindrical rod section could produce reflections that affect AE response. The surface finish should be maintained in a clean, undamaged condition.

4.2 *Hsu-Nielsen Pencil Lead Break Source,* with 2H pencil lead, as described in 4.3.3 of Guide E976.

4.3 *Sensor(s),* to be tested.

4.4 *Acoustic Emission Equipment,* with amplitude measurement capability, for recording sensor response. (Operating familiarity with the apparatus is assumed.)

4.5 *Couplant,* to be standardized and documented by the user of this practice.

5. Procedure

5.1 Ensure that the acrylic rod, sensors and couplant have been allowed to stabilize to the ambient temperature of the examination environment.

5.2 Place the prepared acrylic rod horizontally on a suitable hard, flat surface, such as a benchtop, with the reference mark(s) facing vertically up (12 o’clock). The rod may be secured with tape or other means no closer than 30.5 cm [12 in.] from the reference mark.

5.3 Prepare and power-up the AE measurement system including preamplifier (if used) and connecting cables; allow warm up time as necessary. Verify the system’s performance. Verification may be accomplished on the rod using a reference sensor that is dedicated to this purpose and not exposed to the hazards of field use; or, it may be accomplished by electronic procedures such as those described in Practice E750 or Guide E2374.

5.4 Mount the sensor to be tested on the flat end of the rod using the prescribed couplant and normal good application techniques (refer to Guide E650). Wipe off old couplant before mounting. Mount the sensor in the six o’clock position so that it is resting on the same surface supporting the acrylic rod. This will prevent slipping of the sensor during sensor verification. If the sensor is a side connector type, have the connector pointing in the 3 o’clock direction as shown in Fig. 1.

5.5 Using the pencil lead source, break lead with the end of the lead in the center of the reference mark, within 0.5 mm [0.020 in.] with a lead extension of 2.5 ± 0.5 mm [0.1 ± 0.02 in.]. A Nielsen shoe may be used to obtain a consistent 30° angle between the lead and the surface. Hold the pencil pointing towards the sensor but with its axis approximately 22° (a quarter of a right angle) off from the axis of the rod, so that the lead flies off to one side and does not hit the sensor. Fingers may be rested on the rod on the side away from the sensor to steady the pencil, but there must be no finger contact or other materials in contact with the rod between pencil and sensor, except for the hard surface on which the acrylic rod is resting. As a general guide, use the 10.2 cm [4 in.] reference mark when breaking 0.3 mm [0.012 in.] pencil lead and the 30.5 cm [12.0 in.] reference mark when using 0.5 mm [0.02 in.] pencil lead. If using the 10.2 cm [4.0 in.] reference mark and the sensor amplitude response is 90 dB or greater, move to the 30.5 cm [12 in.] reference mark instead to avoid possible saturation effects, which might compromise the test results.

5.6 Make three consistent lead breaks for each sensor, recording amplitude responses on a sensor performance verification form, similar to that shown in Appendix X1. As a general rule, determine the average sensor amplitude response and proceed to the next sensor.

5.7 Acceptance criteria, which should be assigned prior to conducting this practice by the testing organization, should be documented, for example as shown in Appendix X1, and applied to the sensor data recorded. Sensors failing the criteria should not be used during the examination, and should be returned for a more comprehensive analysis, repaired or discarded.

6. Precision and Bias

6.1 Temperature variations are known to affect the acoustic absorption properties of the acrylic rod. However, since this is a comparative technique rather than an absolute one, this practice can be carried out with good results if all component parts used in the practice have been allowed to stabilize to the examination (environmental) temperature prior to application.

6.2 Person-to-person variations can be reduced to a range of 1 dB by proper technique and training.

6.3 Variations in fracture performance within a lead and between leads are possible. With experience, occasional bad breaks often can be identified by the operator, even without reference to the results of the measurement.

6.4 Bad breaks are relatively common as the pencil is about to run out of lead.

6.5 While uniformity of material is a major quality goal of the lead manufacturer, runs of bad lead can occur due to manufacturing variations.

7. Keywords

7.1 acoustic emission sensors; AE; sensor check; sensor consistency check; sensor response; sensor test; sensor verification

APPENDIX

(Nonmandatory Information)

X1. Sensor Performance Verification Form

See Fig. X1.1.

DATE: ______________ Start/End Times: ____________________ Job ID: ______________

OPERATOR(S): ___________________________ AMBIENT TEMPERATURE: ______________

PENCIL LEAD DIA: ___________LEAD HARDNESS: _________________ SHOE: Y/N _______

SYSTEM MANUFACTURER MODEL: ____

SYSTEM SERIAL#: ____________________________ CHANNEL # __________

ROD ID: ____

SENSOR COUPLANT: _________________________ SENSOR CABLE LENGTH: ______________

Sensor Model, SN#	Amplitudes (dB_{AE})					Avg.	Sensor Model, SN#	Amplitudes (dB_{AE})					Avg.

AVG. AMPL. OF ALL SENSORS: ______dB ACCEPTANCE CRITERIA: +/− 2 dB of Average Amplitude

COMMENTS/NOTES: ____

____

____

FIG. X1.1 Example of Sensor Performance Verification Form

(19)

ARTICLE 30
TERMINOLOGY FOR NONDESTRUCTIVE EXAMINATIONS STANDARD

DELETED

ARTICLE 31
ALTERNATING CURRENT FIELD MEASUREMENT STANDARD

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STANDARD PRACTICE FOR EXAMINATION OF WELDS USING THE ALTERNATING CURRENT FIELD MEASUREMENT TECHNIQUE

(**19**)

SE-2261/SE-2261M

(Identical with ASTM Specification E2261/E2261M-17.)

Standard Practice for Examination of Welds Using the Alternating Current Field Measurement Technique

1. Scope

1.1 This practice describes procedures to be followed during alternating current field measurement examination of welds for baseline and service-induced surface breaking discontinuities.

1.2 This practice is intended for use on welds in any metallic material.

1.3 This practice does not establish weld acceptance criteria.

1.4 *Units*—The values stated in either inch-pound units or SI units are to be regarded separately as standard. The values stated in each system might not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standard:*

SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *ISO Standard:*

ISO 9712 Nondestructive Testing—Qualification and Certification of Nondestructive Testing Personnel

3. Terminology

3.1 *Definitions*—For definitions of terms relating to this practice refer to Terminology E1316, Section A, Common NDT terms, and Section C, Electromagnetic testing. The following definitions are specific to the alternating current field measurement technique:

3.2 *Definitions:*

3.2.1 *exciter*—a device that generates a time varying electromagnetic field, usually a coil energized with alternating current (AC); also known as a transmitter.

3.2.2 *detector*—one or more coils or elements used to sense or measure a magnetic field; also known as a receiver.

3.2.3 *uniform field*—as applied to nondestructive testing with magnetic fields, the area of uniform magnetic field over the surface of the material under examination produced by a parallel induced alternating current, which has been passed through the weld and is observable beyond the direct coupling of the exciting coil.

3.2.4 *graduated field*—as applied to nondestructive testing with magnetic fields, a magnetic field having a controlled gradient in its intensity.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *alternating current field measurement system*—the electronic instrumentation, software, probes, and all associated components and cables required for performing weld examination using the alternating current field measurement technique.

3.3.2 *operational reference standard*—a reference standard with specified artificial slots, used to confirm the operation of the system.

3.3.3 *Bx*—the x component of the magnetic field, parallel to the weld toe, the magnitude of which is proportional to the current density set up by the electric field.

3.3.4 *Bz*—the z component of the magnetic field normal to the inspected base metal/heat affected zone surface, the magnitude of which is proportional to the lateral deflection of the induced currents in the plane of that surface.

3.3.5 *X-Y Plot*—an X-Y graph with two orthogonal components of magnetic field plotted against each other.

3.3.6 *time base plots*—these plot the relationship between Bx or Bz values with time.

3.3.7 *surface plot*—for use with array probes. This type of plot has one component of the magnetic field plotted over an area, typically as a color contour plot or 3-D wire frame plot.

3.3.8 *data sample rate*—the rate at which data is digitized for display and recording, in data points per second.

3.3.9 *configuration data*—standardization data and instrumentation settings for a particular probe stored in a computer file.

3.3.10 *twin fields*—magnetic fields generated in two orthogonal directions by use of two exciters

NOTE 1—Different equipment manufacturers may use slightly different terminology. Reference should be made to the equipment manufacturer's documentation for clarification.

4. Summary of Practice

4.1 In a basic alternating current field measurement system, a small probe is moved along the toe of a weld. The probe contains an exciter coil, which induces an AC magnetic field in the material surface aligned to the direction of the weld. This, in turn, causes alternating current to flow across the weld. The depth of penetration of this current varies with material type and frequency but is typically 0.004 in. [0.1 mm] deep in magnetic materials and 0.08 to 0.3 in. [2 to 7 mm] deep in non-ferrous materials. Any surface breaking discontinuities within a short distance of either side of the scan line at this location will interrupt or disturb the flow of the alternating current. The maximum distance from the scan line to a target discontinuity, potentially detectable at a specified probability of detection, is determined by the probe assembly size, but is typically 0.4 in [10 mm]. Measurement of the absolute quantities of the two major components of the surface magnetic fields (Bx and Bz) determines the severity of the disturbance (see Fig. 1) and thus the severity of the discontinuity. Discontinuity sizes, such as crack length and depth, can be estimated from key points selected from the Bx and Bz traces along with the standardization data and instrument settings from each individual probe. This discontinuity sizing can be performed automatically using system software. Discontinuities essentially perpendicular to the weld may be detected (in ferritic metals only) by the flux leakage effect. However confirmation of such transverse discontinuities (and detection of the same in non-ferritic metals) requires scans with the induced magnetic field perpendicular to the direction of the weld.

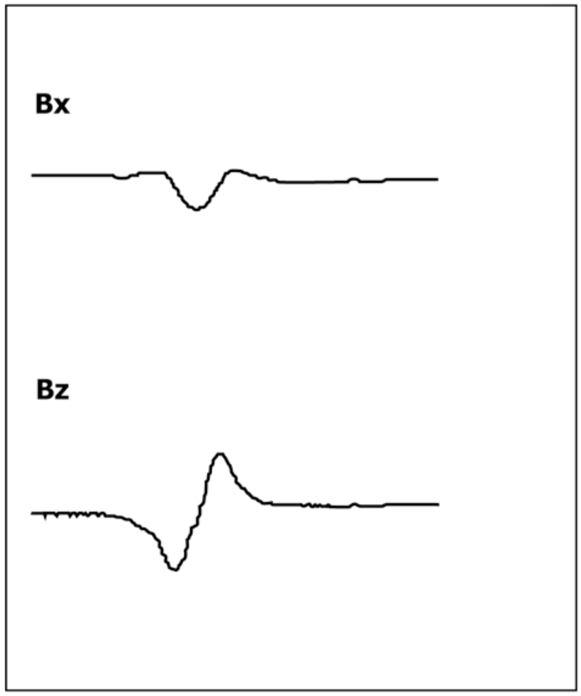


FIG. 1 Example Bx and Bz Traces as a Probe Passes Over a Crack
(The orientation of the traces may differ depending upon the instrumentation.)

4.2 Configuration data is loaded at the start of the examination. System sensitivity and operation is verified using an operation reference standard. System operation is checked and recorded prior to and at regular intervals during the examination. Note that when a unidirectional input current is used, any decay in strength of the input field with probe lift-off or thin coating is relatively small so that variations of output signal (as may be associated with a discontinuity) are reduced. If a thick coating is present, then the discontinuity size estimation must compensate for the coating thickness. The coating thickness requiring compensation is probe dependent. This can be accomplished using discontinuity-sizing tables in the system software and an operator-entered coating thickness or automatically if the equipment measures the coating thickness or stand-off distance during the scanning process. Using the wrong coating thickness would have a negative effect on depth sizing accuracy if the coating thickness discrepancy is too large. Data is recorded in a manner that allows archiving and subsequent recall for each weld location. Evaluation of examination results may be conducted at the time of examination or at a later date. The examiner generates an examination report detailing complete results of the examination.

5. Significance and Use

5.1 The purpose of the alternating current field measurement method is to evaluate welds for surface breaking discontinuities such as fabrication and fatigue cracks. The examination results may then be used by qualified organizations to assess weld service life or other engineering characteristics (beyond the scope of this practice). This practice is not intended for the examination of welds for non-surface breaking discontinuities.

6. Basis of Application

6.1 *Personnel Qualification:*

6.1.1 If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, ISO 9712, or a similar document and certified by the employer or certifying agent, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Evaluation Agencies*—if specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543, with reference to sections on electromagnetic examination. The applicable edition of Practice E543 shall be specified in the contractual agreement.

7. Job Scope and Requirements

7.1 The following items may require agreement by the examining party and their client and should be specified in the purchase document or elsewhere:

7.1.1 Location and type of welded component to be examined, design specifications, degradation history, previous nondestructive examination results, maintenance history, process conditions, and specific types of discontinuities that are required to be detected, if known.

7.1.2 The maximum window of opportunity for work. (Detection of small discontinuities may require a slower probe scan speed, or cleaning of surface, or both, which will affect productivity.)

7.1.3 Size, material grade and type, and configuration of welds to be examined. If required by type of equipment chosen, thickness of coating and variation of coating thickness.

7.1.4 A weld numbering or identification system.

7.1.5 Extent of examination, for example: complete or partial coverage, which welds and to what length, whether straight sections only and the minimum surface curvature.

7.1.6 Means of access to welds, and areas where access may be restricted.

7.1.7 Type of alternating current field measurement instrument and probe; and description of operations referece standard used, including such details as dimensions and material.

7.1.8 Required operator qualifications and certification.

7.1.9 Required weld cleanliness.

7.1.10 Environmental conditions, equipment and preparations that are the responsibility of the client; common sources of noise that may interfere with the examination.

7.1.11 Complementary methods or techniques may be used to obtain additional information.

7.1.12 Acceptance criteria to be used in evaluating discontinuities.

7.1.13 Disposition of examination records and reference standards.

7.1.14 Format and outline contents of the examination report.

8. Interferences

8.1 This section describes items and conditions, which may compromise the alternating current field measurement technique.

8.2 *Material Properties:*

8.2.1 Although there are permeability differences in a ferromagnetic material between weld metal, heat affected zone and parent plate, the probe is normally scanned along a weld toe and so passes along a line of relatively constant permeability. If a probe is scanned across a weld then the permeability changes may produce indications, which could be similar to those from a discontinuity. Differentiation between a transverse discontinuity signal and the weld signal can be achieved by taking further scans parallel to the indication, or using an array probe. The signal from a discontinuity will die away quickly. If there is no significant change in indication amplitude at 0.8 in. [20 mm] distance from the weld then the indication is likely due to the permeability changes in the weld.

8.3 *Magnetic State:*

8.3.1 *Demagnetization*—It must be ensured that the surface being examined is in the non-magnetized state. Therefore the procedure followed with any previous magnetic technique deployed must include demagnetization of the surface. This is because areas of remnant magnetization, particularly where the leg of a magnetic particle examination yoke was sited, can produce loops in the X-Y plot, which may sometimes be confused with a discontinuity indication.

8.3.2 *Grinding marks*—magnetic permeability can also be affected by surface treatments such as grinding. These can cause localized areas of altered permeability across the line of scan direction. The extent and pressure of any grinding marks should always be reported by the probe operator, since these can give rise to strong indications in both Bx and Bz, which may be confused with a discontinuity indication. If a discontinuity is suspected in a region of grinding, further scans should be taken parallel but away from the weld toe and perpendicular across the region of grinding. The indication from a linear discontinuity will die away quickly away from the location of the discontinuity so that the scan away from the weld toe will be flatter. If there is no significant change in indication amplitude at 0.80 in. [20 mm] distance from the weld then the indication is likely due to the effect of the grinding. The indication from a region of grinding will be the same for the perpendicular scan.

8.4 Residual stress, with accompanying permeability variations, may be present with effects similar to those due to grinding, but are much smaller.

8.5 *Seam Welds:*

8.5.1 Seam welds running across the line of scanning also produce strong indications in the Bx and Bz, which can sometimes be confused, with a discontinuity indication. The same procedure is used as for grinding marks with further scans being taken away from the affected area. If the indication remains constant then it will not have been produced by a linear discontinuity.

8.6 *Ferromagnetic and Conductive Objects:*

8.6.1 Problems may arise because of objects near the weld that are ferromagnetic or conductive which may reduce the sensitivity and accuracy of discontinuity characterization when they are in the immediate vicinity of the weld.

8.7 *Neighboring Welds:*

8.7.1 In areas where welds cross each other, there are indications, which may be mistaken for discontinuities. (See 8.5.)

8.8 *Weld Geometry:*

8.8.1 When a probe scans into a tight angle between two surfaces the Bx indication value will increase with little change in the Bz value. In the representative plot of Fig. 2, this appears as a rise in the X-Y plot. If the equipment is capable of measuring lift-off, the lift-off will also change.

8.9 *Crack Geometry Effects:*

8.9.1 *A discontinuity at an angle to the scan*—a discontinuity at an angle to the scan will reduce either the peak or the trough of the Bz as the sensor probe only passes through the edge of one end of the discontinuity. This produces an asymmetric X-Y plot. Additional scans may be made along the weld or parent plate to determine the position of the other end of the discontinuity.

8.9.2 *A discontinuity at an angle to the surface*—the effect of a discontinuity at a non-vertical angle to the probe is generally to reduce the value of the Bz signal. The value of the Bx signal will not be reduced. This has the effect of reducing the width of the X-Y plot in the representative plot of Fig. 2.

8.9.3 *Line contact or multiple discontinuities*—when contacts occur across a discontinuity then minor loops occur within the main X-Y plot loop produced by the discontinuity. If more than one discontinuity occurs in the scan then there will be a number of loops returning to the background.

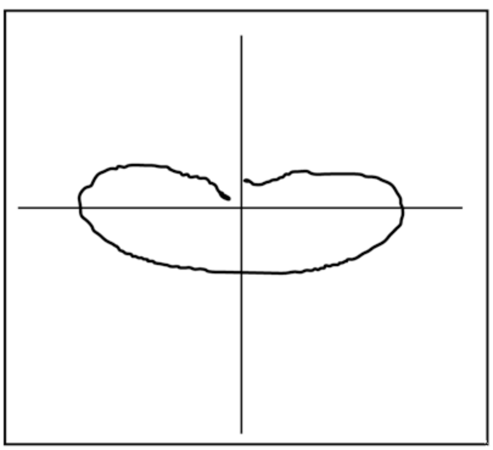


FIG. 2 Example X-Y Plot Produced by Plotting the Bx (vertical) and Bz (horizontal) Together
(The orientation of the plot may differ depending upon the instrumentation.)

8.9.4 *Transverse discontinuities*—if a transverse discontinuity occurs during the scan for longitudinal discontinuities then the Bx may rise instead of falling and the Bz signal will remain the same as for a short longitudinal discontinuity. The X-Y plot will then go upwards instead of down in the representative plot of Fig. 2. This flux leakage effect is, however, related to the opening of the discontinuity, so it may not be seen for tightly closed discontinuities. To confirm the presence of transverse discontinuities, further scans should be made with the probe orientated to give an induced field perpendicular to the weld, or through use of an array probe with twin fields.

8.9.5 Alternating current field measurement end effect - the field from the standard weld probe is able to propagate around the end of a weld and this can result in sloping changes in the Bx and Bz traces. A discontinuity indication may be obscured or distorted if the discontinuity or any active probe element is close to the weld end. The distance over which this effect occurs depends on probe type, but can be up to 2 in. [50 mm] for large probes. Smaller probes should be used in these situations as they have less susceptibility to edge effect.

8.10 *Instrumentation:*

8.10.1 The operator should be aware of indicators of noise, saturation or signal distortion particular to the instrument being used. Special consideration should be given to the following concerns:

8.10.1.1 The excitation frequency of operation should be chosen to maximize discontinuity sensitivity whilst maintaining acceptable noise levels.

8.10.1.2 Saturation of electronic components is a potential problem in alternating current field measurement because signal amplitude can increase rapidly as a probe is scanned into tight angle geometry. This could cause the Bx indication to rise above the top of the range of the A/D converter in the instrument. Data acquired under saturation conditions is not acceptable and appears as a flattening of the Bx response in the representative plots of Fig. 1 at the maximum possible signal value. If saturation conditions are observed, the equipment gain should be reduced until the Bx value no longer appears to saturate and the inspection repeated. After adjusting the equipment gain, an equipment operation check as described in 11.2 is recommended, except that the loop size will be smaller. Note that this gain adjustment does not affect the discontinuity sizing capability.

8.10.2 *Instrument-induced Phase Offset*—The measurements of magnetic field are at a chosen and fixed phase so that unlike during conventional eddy current examination the phase angle does not need to be considered. The phase is selected at manufacture of the probes and is stored in the probe file and is automatically configured by the instrument.

8.11 *Coating Thickness*

8.11.1 If a coating thickness exceeds the specified range for uncompensated operation then the discontinuity size estimation must compensate for the coating thickness. This can be accomplished by manually entering a coating thickness and using discontinuity tables in the system software. Otherwise, using the wrong coating thickness would reduce the depth sizing accuracy. Alternatively, the compensation may be performed automatically if the equipment measures the stand-off distance or coating thickness during the scanning process.

9. Alternating Current Field Measurement System

9.1 *Instrumentation*

9.1.1 The electronic instrumentation shall be capable of energizing the exciter at one or more frequencies appropriate to the weld material. The apparatus shall be capable of measuring the Bx and Bz magnetic field amplitudes at each frequency. The instrument will be supplied with a processor, either internally, or in the form of a portable personal computer (PC), that has sufficient system capabilities to support the alternating current field measurement software, which will be suitable for the instrument and probes in use and the examination requirements. The software provides control of the instrumentation including set-up, data acquisition, data display, data analysis and data storage. The software provides algorithms for sizing the discontinuities (see 11.2.2). The software runs on the processor and, on start up, all communications between the processor and the instrument are automatically checked. When the software starts up it automatically sets up the instrument connected in the correct mode for alternating current field measurement examination. Configuration data for each probe is stored either on the processor or on the probe and is transmitted to the instrument whenever a probe is selected or changed. For non-magnetic materials, if configuration data is not available from the equipment manufacturer, a standardization may be performed on reference blocks prior to the material examination. Equipment operation is also checked by scanning over a reference standard (see 11.2.2). Once the instrumentation is set up for a particular probe, the software can be used to start and stop data acquisition. During data acquisition at least two presentations of the data are presented on the display screen in real time (see 4.1). Data from the probe is displayed against time (with Fig. 1 as an example) and also as an X-Y plot (with Fig. 2 as an example). The data from the probe can also be displayed against position (see Fig. 1) if an encoder is used with the probe. Depending upon equipment type, manual or automatic position markers may be incorporated with the data. Once collected the data can be further analyzed offline using the software to allow, for example, discontinuity sizing (see 11.2.2) or annotation for transfer to examination reports. The software also provides facilities for all data collected to be electronically stored for subsequent review or reanalysis, printing or archiving.

9.2 *Driving Mechanism:*

9.2.1 When a mechanized system is in operation, a mechanical means of scanning the probe, or probes in the form of an array, along a weld or surface area at approximately constant speed may be used.

9.3 *Probes:*

9.3.1 The probes selected should be appropriate for the form of examination to be carried out dependent on length of weld, geometry, size of detectable discontinuity and surface temperature.

9.3.1.1 *Standard weld probe*—commonly used for weld examination whenever possible as it has its coils positioned ideally for discontinuity sizing.

9.3.1.2 *Tight access probe*—designed specifically for occasions where the area under examination is not accessible with the standard weld probe. It is not as accurate as the weld probe for sizing in open geometries such as butt welds.

9.3.1.3 *Grind repair probe*—designed for the examination of deep repair grinds. It has the same basic geometry as a standard probe but is more susceptible to produce indications from vertical probe movement.

9.3.1.4 *Mini-probe*—designed for restricted access areas such as cut outs and cruciforms and has a reduced edge effect. It may be limited to shallow discontinuities only and is more sensitive to lift off. This probe may be in the form of a straight entry or 90°.

9.3.1.5 *Micro-probe*—designed for high-sensitivity discontinuity detection in restricted access areas and has the same limitations as a mini-probe. This probe may be in the form of a straight entry or 90°.

9.3.1.6 *Array probe*—made up of a number of elements; each element is sensitive to a discrete section of the weld width. The elements may be oriented with their axes aligned longitudinally or transversely with respect to the weld toe. The array probe may have two orthogonal field exciters to allow examination for longitudinal and transverse discontinuities in a single scan. The array probe is generally used either for scanning a weld cap in one pass or for covering a section of plate.

9.3.1.7 *Edge effect probe*—designed to reduce the edge effect when carrying out examination only near the ends of welds. (A mini probe may also be used for the same examination.)

9.4 *Data Displays:*

9.4.1 The data display should include Bx and Bz indications as well as an X-Y plot.

9.4.2 When multi-element array probes are being used, the facility to produce color contour maps or 3D-wire frame plots representing peaks and troughs should be available.

9.5 *Excitation Mechanism:*

9.5.1 The degree of uniformity of the magnetic field applied to the material under examination is determined by the equipment manufacturer. Representative magnetic field distributions are a uniform magnetic field and a graduated magnetic field. The geometry of the slots used in the operation reference standard and the discontinuity sizing model must be consistent with the excitation field.

10. Alternating Current Field Measurement Reference Standards

10.1 *Artificial Slots for the Operation Reference Standard:*

10.1.1 The operation reference standard has specific artificial discontinuities. It is used to check that the instrument and probe combination is functioning correctly. It may also be used for standardization of the equipment for nonmagnetic materials. Unless otherwise specified by the client or equipment manufacturer, the artificial discontinuities for the operation reference standard are elliptical or rectangular slots. The slot geometry will be specified by the equipment manufacturer to be consistent with the crack size estimation model. Typical slot dimensions are as follows:

10.1.1.1 *Elliptical Slots*—Two elliptical slots placed in the weld toe with dimensions 2.0 in. × 0.2 in. [50mm × 5mm] and 0.8 in. × 0.08 in. [20 mm × 2 mm]. (Fig. 3, discontinuities A and B.)

10.1.1.2 *Rectangular Slots*—Three rectangular slots with depth 0.08 in. [2 mm] and lengths of 0.4 in. and 0.8 in. [10 mm and 20 mm] (Fig. 3, discontinuities C and D) and with depth 0.16 in. [4 mm] and length of 1.6 in. [40 mm] (Fig. 3, discontinuity E.)

10.1.2 These slots shall be less than 0.008 in. [0.2 mm] wide.

10.1.3 Artificial discontinuity depths are specified by giving the deepest point of the discontinuity. Discontinuity depths shall be accurate to within ±10% of the depth specified, measured, and documented. The discontinuity length shall be accurate to within ±0.040 in. [±1.00 mm] of the dimension specified.

10.2 Reference standards having artificial or simulated discontinuities are not required for standardization when the technique is to be used to examine carbon steel welds or if configuration data is available for the examination material.

10.3 *Materials other than carbon steel:*

10.3.1 If the technique is to be used on materials other than carbon steel, then it may be necessary to standardize the probes on this material if configuration data is not available from the equipment manufacturer, refer to manufacturer's instructions.

NOTE 2—If this is not done then the sizes of the indications may be too small (so that small discontinuities may be missed) or too large (so that spurious indications may be called), or the Bx indication may saturate making the examination invalid. This standardization is done using a slot

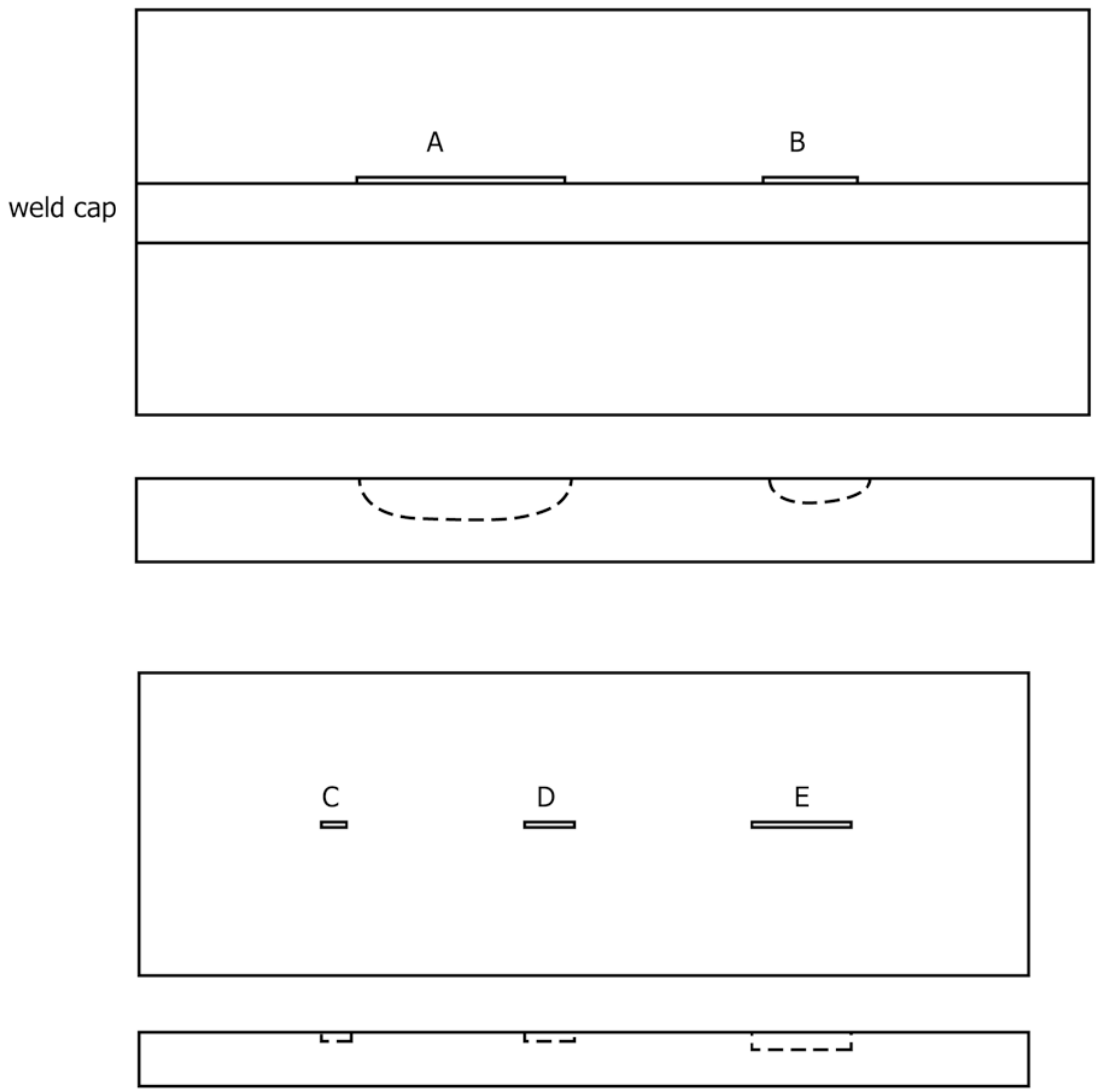


FIG. 3 Flat Plate Sample Serial Number XXX Showing Size and Location of Reference Slots (Plan View and Side View. Not to Scale)

of reasonable size located at a weld toe of a representative sample. The gain settings are altered, either automatically or manually according to equipment type, until a loop of reasonable size is produced in the X-Y plot while background noise indications are kept low. When the technique is to be used to size the depths of discontinuities detected in material for which configuration data is unavailable, then a reference standard should be manufactured from the material with at least two slots of differing depth. This provides an adjustment coefficient that modifies the estimated depth from the sizing model.

10.4 Reference standards having artificial or simulated discontinuities for welds in materials other than carbon steel shall not be used for discontinuity characterization unless the signals from the artificial discontinuities can be demonstrated to be similar to the signals for discontinuities detected. To be considered similar, a direct comparison should be performed between responses to the simulated discontinuities and real cracks. This comparison should involve at least one limited sizing trial or a probability of detection (POD) study.

10.5 *Manufacture and Care of the Operation Reference Standards:*

10.5.1 *Drawings*—for each operation reference standard and standard, there shall be a drawing that includes the as-built measured slot dimensions, material type and grade, and the serial number of the actual operation reference standard or weld standard.

10.5.2 *Serial Number*—each operation reference standard shall be identified with a unique serial number and stored so that it can be obtained and used for reference when required.

10.5.3 *Slot Spacing*—the slots should be positioned longitudinally to avoid overlapping of indications and interference from end effects.

10.5.4 Proper machining practices shall be used to avoid excessive cold-working, over-heating, and undue stress and permeability variations.

10.5.5 Blocks should be stored and shipped so as to prevent mechanical damage.

11. Equipment Operation Check

11.1 *Instrument Settings:*

11.1.1 *Operating Frequency*—using the appropriate operation reference standard the procedure in 11.2.2 below is intended to help the user select an operating frequency. Demonstrably equivalent methods may be used. The standard operating frequency depends upon the equipment to be used and typically is in the range of 5 to 50 kHz. A higher operating frequency will give better sensitivity on good surfaces. If the system available is not capable of operating at the frequency described by this practice, the inspector shall declare to the client that conditions of reduced sensitivity may exist.

11.1.2 *Standardization*—For non-magnetic materials where configuration data is not available, the equipment may need to be standardized. Standardization is performed by loading manufacturer supplied configuration data, performing standardization measurements, and saving the resulting data and instrument settings as user configuration data. The standardization measurements are performed using the appropriate operation reference standard (see 10.1). The probe is placed at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld. The probe is then scanned across the operation reference standard and over a reference slot as specified by the equipment manufacturer. The signal for the scanned slot is then selected and the gain is adjusted manually or automatically based on the measured signal and a reference signal for the discontinuity. Care must be used to ensure that the reference slot is the same as the discontinuity for the reference signal. This information can then be saved as user configuration data.

11.2 *Test System Check and Procedure:*

11.2.1 The test system shall consist of an alternating current field measurement instrument, a PC (if required), the probe and the operation reference standard.

11.2.2 The equipment operation check will be performed using the appropriate operation reference standard (see 10.1). The probe is placed at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld. The probe is then scanned across the operation reference standard and over the appropriate reference slot, which depends upon the probe type and as specified by the equipment manufacturer producing a standardized data plot. Discontinuity indications are created when (1) the background level Bx value is reduced and then returns to the nominal background level (see Fig. 1) and this is associated with (2) a peak or positive (+ve) indication followed by a trough or negative (-ve) indication (or a trough followed by a peak, depending on direction of scan) in the Bz values. The resultant effect of the changes in Bx and Bz is a loop in the X-Y plot shown, for example, as the downward loop of Fig. 2. The presence of a discontinuity is confirmed when all three of these indications are present, that is, changes in the Bx and the Bz values and a loop in the X-Y plot. The loop should fill approximately 50 % of the Bx direction and 175 % of the Bz direction of the X-Y plot (that is, the loop is larger than the display in the Bz direction). The scanning speed or data sampling rate can then be adjusted if necessary, depending on the length and complexity of weld to be examined.

11.2.2.1 Once the presence of the discontinuity has been confirmed by the Bx and Bz indications the discontinuity should be sized.

11.2.2.2 Discontinuity sizing is performed in the examination software and uses look-up tables of expected responses versus discontinuity sizes. These tables are based upon mathematical models that simulate the current flow around the discontinuities and the resultant change in surface magnetic field. The operator either positions cursors on the displayed data or enters background and minimum values of Bx along with the Bz length and any coating thickness to allow the software to estimate discontinuity length and depth.

11.2.2.3 If the discontinuity sizing values differ from those expected from the operation reference standard then the instrument and probe settings should be checked. Each probe should have a unique probe file, the validity of which has been checked against the discontinuity sizing tables. The instrument settings can be checked using the software package.

11.2.3 Each alternating current field measurement unit and probe to be used during the examination should be checked with the operation reference standard. Discontinuity sizing estimation results obtained should be the same as the measured dimensions of the slots in the block. If the dimensions differ by more a specified margin (for example, 10 %), then check that the correct probe files and gain have been used. If the correct probe files and gain have been used then there is a fault with the system, which will have to be determined. Do not use for examination unless standardization validity is confirmed within the specified margin between the estimated and measured slot dimensions.

11.3 *Frequency of System Checks:*

11.3.1 The system should be checked with all of the probes to be used during the examination prior to examining the first weld.

11.3.2 System operation should be checked at least every four hours with the probe in use or at the end of the examination being performed. If the discontinuity responses from the operation reference standard have changed by a specified margin (for example, 10 %), the welds examined since the last operations reference standard check shall be re-examined after following the procedure in 11.2.3.

12. Examination Procedure

12.1 If necessary, clean the weld surface to remove obstructions and heavy ferromagnetic or conductive debris.

12.2 Following the guidelines in 9.3, select a suitable probe for the examination task, then, using the installed software, select a data file and a probe file.

12.2.1 The probe is placed at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld.

12.2.2 The probe is then scanned along the weld. Discontinuity indications are created when the following three points are indicated:

12.2.2.1 The background level Bx value is reduced and then returns to the nominal background level, Fig. 1.

12.2.2.2 This is associated with a peak, or positive (+ve) indication followed by a trough, or negative (-ve) indication (or a trough followed by a peak, depending on direction of scan) in the Bz values. Fig. 1.

12.2.2.3 The resultant effect of the changes in Bx and Bz is a downward loop in the X-Y plot, which is shown as a downward loop in the exmple plot of Fig. 2.

12.2.3 The presence of a discontinuity is confirmed when all three of these indications are present, that is, the Bx, the Bz and a loop in the X-Y plot. The scanning speed or data sampling rate can be adjusted if necessary, depending on the length and complexity of weld to be examined.

12.3 *Compensation for Material Differences:*

12.3.1 To compensate for the small differences in readings caused by variations in permeability, conductivity or geometry for a given material, the data may be centered on the display area. For larger differences, the equipment settings should be adjusted, and/or a more suitable probe configuration should be used, in accordance with the manufacturer's instructions.

12.4 *Compensation for Ferromagnetic or Conductive Objects:*

12.4.1 Techniques that may improve alternating current field measurement results near interfering ferromagnetic or conductive objects include:

12.4.1.1 Comparison of baseline or previous examination data with the current examination data.

12.4.1.2 The use of special probe coil configurations.

12.4.1.3 Use of higher or lower frequency probes may suppress non-relevant indications.

12.4.1.4 The use of a complementary method or technique.

12.5 Size and record all discontinuity indications as described in Section 14.

12.6 Note areas of limited sensitivity, using indications from the operation reference standard as an indicator of discontinuity detectability.

12.7 Using a discontinuity characterization standard, evaluate relevant indications in accordance with acceptance criteria specified by the client, if applicable.

12.8 If desired, examine selected areas using an appropriate complementary method or technique to obtain more information, adjusting results where appropriate.

12.9 Compile and present a report to the client.

13. Examination Considerations

13.1 *Scanning Speed:*

13.1.1 The scanning speed is chosen using the appropriate data sampling rate to obtain reasonable fidelity with the details of the scanned object given the length of the shortest discontinuity required to be found. A typical scan speed is 1 in. [25 mm]/second. This will produce a regular scan on the display screen. If short welds are to be examined then a faster data sampling rate should be used. If long welds are to be examined and the whole weld needs to be seen on the display screen then a slower data-sampling rate should be used. The weld length and speed of scanning will govern the data-sampling rate selected. With the introduction of faster software or hardware it is possible to select respective data sampling rates to produce faster scanning rates.

13.1.2 Acquire and record data from the operation reference standard at the selected examination speed.

13.1.3 Acquire and record data from the welds to be examined. Maintain as uniform a probe speed as possible throughout the examination to produce repeatable indications.

13.2 *Width of Scan:*

13.2.1 The scan width is determined by the size of the probe and should be considered when performing an inspection. The sensitivity of the probe to a discontinuity decreases with distance. This distance is a factor that affects the number of scans that must be performed in order to provide full coverage when inspecting the weld. Note that even if a scan width is larger than the width of the weld cap, both toes of the weld should be scanned separately in most cases.

13.3 *Continuous Cracking:*

13.3.1 Prior to the scanning of a weld, checks should be made that the discontinuity is not continuous by scanning the probe from 2 in. [50 mm] away from the weld towards the toe. If a discontinuity is present the Bx indication on the computer screen will dip as the probe approaches the weld toe. If this form of indication occurs then this procedure shall be repeated at intervals along the toe of the weld.

13.4 *Scanning Direction:*

13.4.1 The probe should always be scanned parallel to the weld toe (except when confirming transverse discontinuities or discontinuities in regions of grinding) and this will give recognizable indications from longitudinal discontinuities in the weld area. Scanning in this direction will also give recognizable indications from transverse discontinuities and discontinuities inclined to the toe of the weld. The operator should be familiar with these types of indications.

13.5 *Circumferential Welds:*

13.5.1 The scanning pattern for a circumferential weld is shown in Fig. 4. Overlapping scans are required to ensure no discontinuities are missed if they occur at the end of a scan. The number of overlapping scans will vary depending on the component diameter. The overlap should be between 1 in. [25 mm] and 2 in. [50 mm] depending on the diameter of the tube or pipe. All detection shall be complete before any sizing operation is performed. Remember to check for continuous discontinuities before scanning.

13.6 *Linear Welds:*

13.6.1 The scanning pattern is similar to that for circumferential welds except that an edge effect may occur at the end of the weld or if the weld ends at a buttress. In the case of the end of the weld an edge-effect probe should be used but for the buttress a mini- or micro-probe should be used. These probes can also be used as an alternative to the edge effect probe. The standard weld probe should be used for sizing if at all possible. Recourse to other techniques, possibly including conventional eddy current techniques, may be necessary in these situations.

13.7 *Attachments, corners and cutouts:*

13.7.1 The scanning patterns for the attachment welds and gussets are shown in Fig. 5, Fig. 6, and Fig. 7 where lines A1-A6, B1-B3 and C1 and 2 are the probe scan lines and positions 1-10 are the incremental positions along the weld length. The corners are difficult to scan and the micro- or mini-probes should be used where possible.

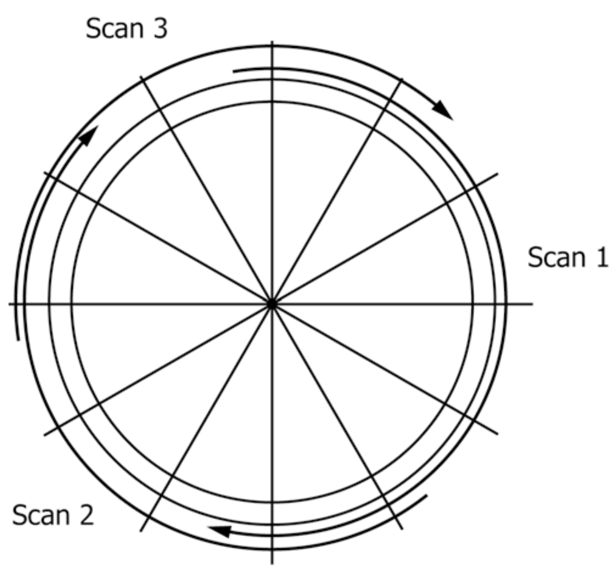


FIG. 4 Scanning Pattern for a Circumferential Weld

13.8 *Cut outs and cruciform geometries:*

13.8.1 The examination of this geometry is difficult due to the access problems; the scanning patterns and identification of the areas are shown in Fig. 8, Fig. 9, Fig. 10 and Fig. 11. The 90° mini- or micro- probe is essential for examining the cut-out areas.

13.9 *Ground-out Areas:*

13.9.1 The repair or groundout area is usually 0.5 in. [12.5 mm] wide, and the grind repair probe is designed for the examination of these areas. The probe should be scanned into one end of the groundout area and the scan continued through the other end. Areas with discontinuities should be noted and sized for length and depth with the grind repair probe.

14. Discontinuity Sizing Procedure

14.1 The depth and length of the discontinuity are estimated from measurements taken of the Bx signatures plus the distance between terminal peak/trough of the Bz signature with compensation provided by either a user entered coating thickness or a real-time thickness compensation function.

14.2 *Length:*

14.2.1 Once an area containing a discontinuity has been located, a repeat scan is taken through the discontinuity. The Bz length of the discontinuity is determined by locating the extreme ends of the discontinuity using the peak (+ve) and trough (-ve) Bz locations. These positions should be just inside the actual ends of the discontinuity. This Bz length is used with the discontinuity sizing tables to determine the true length and depth of the discontinuity. The length of the detected discontinuity may be measured directly by the system software using properly placed manual markers or a position encoder. If the markers are placed manually, then the scan speed should be kept constant.

14.3 *Depth:*

14.3.1 The depth of the discontinuity is calculated using the Bx minimum and Bx background values and the Bz length of the discontinuity measured from the Bz data. Once these values have been put into the discontinuity sizing table, together with the coating thickness, if the equipment does not provide for lift-off compensation, then the discontinuity depth will be estimated by the software. Alternatively, if the equipment provides a lift-off value, the coating thickness can be determined automatically and the depth can be determined from the equipment software and discontinuity sizing table.

15. Report

15.1 *Reporting Requirements*—a list of reporting requirements is given in Table 1. Reference should be made to the Client reporting requirements (7.1.14). The items listed below should be included in the examination report. All information below should be archived, whether or not it is required in the report.

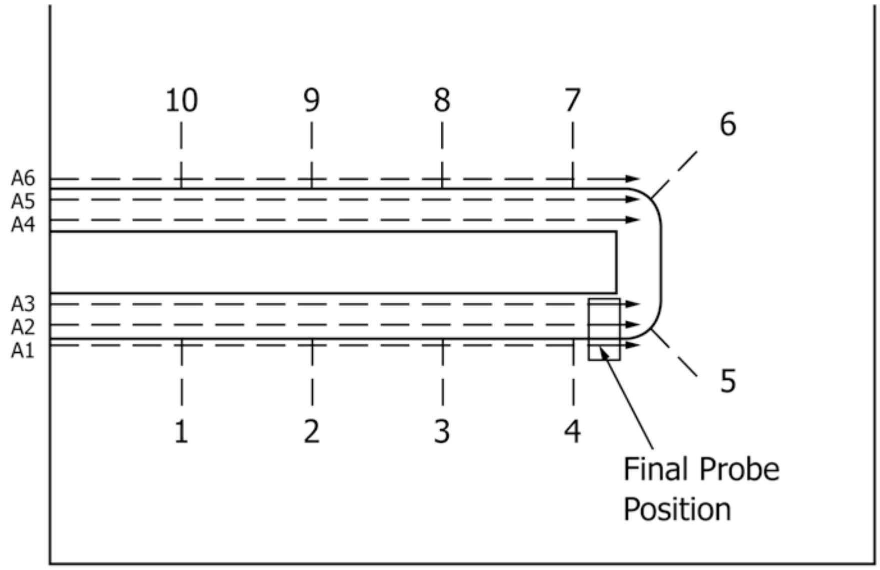


FIG. 5 Scanning Pattern for an Approach to an Attachment

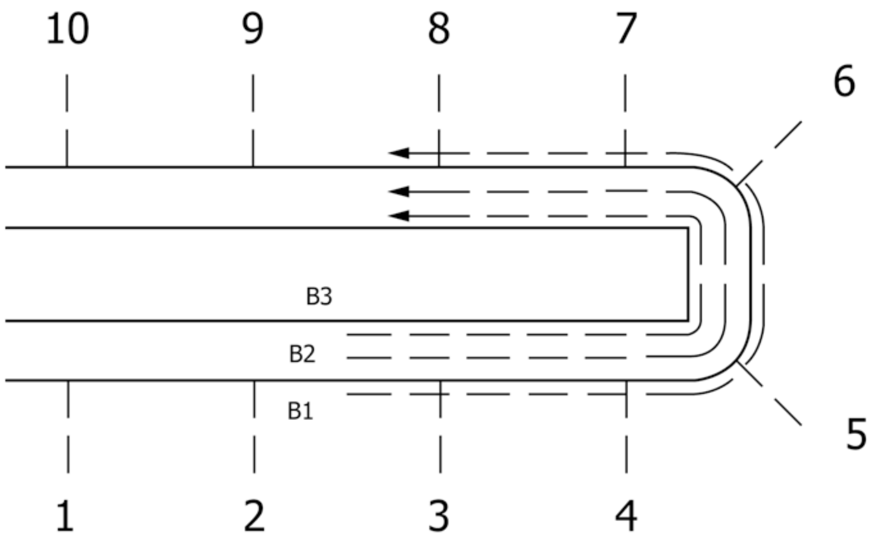


FIG. 6 Scanning Pattern for the End of an Attachment

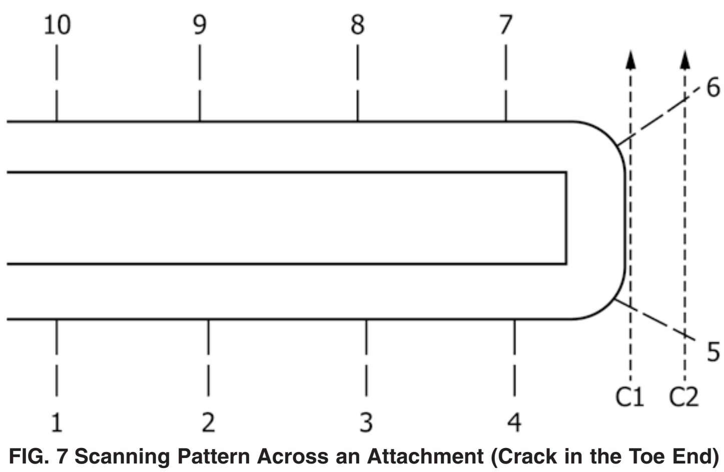


FIG. 7 Scanning Pattern Across an Attachment (Crack in the Toe End)

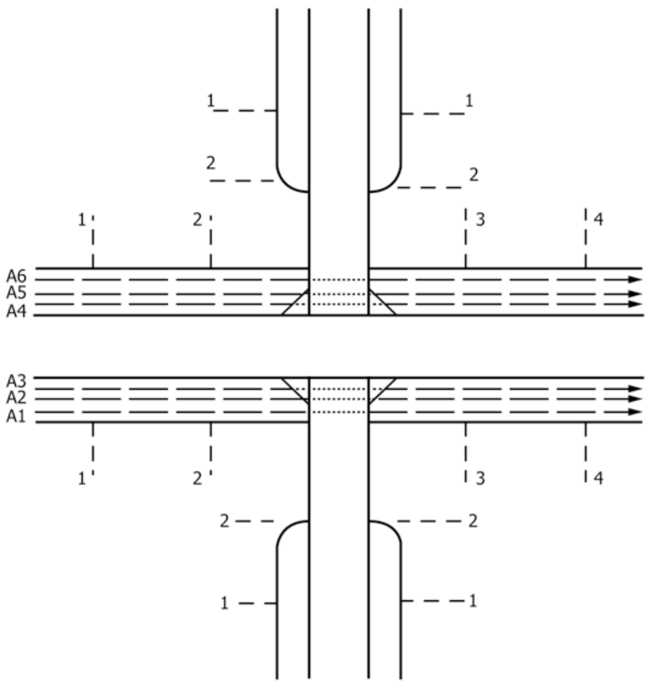


FIG. 8 Scans of the Main Weld

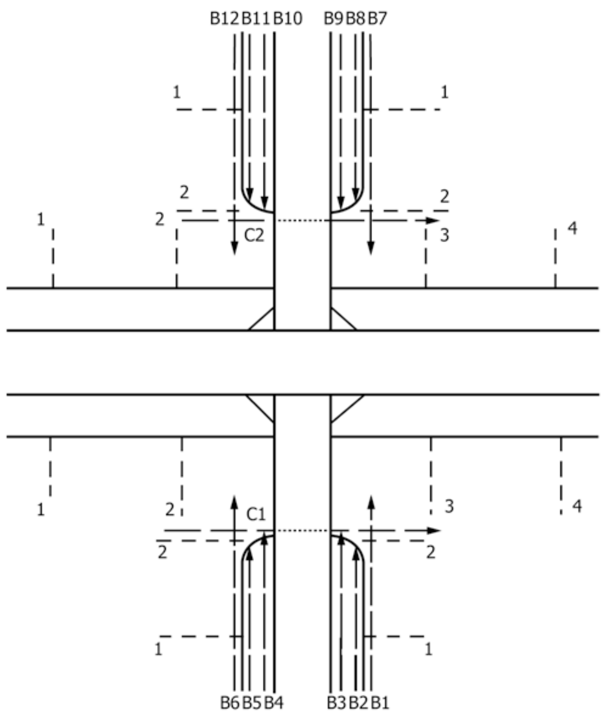


FIG. 9 Scans of the Horizontal Weld into a Cut Out

15.1.1 Owner, location, type and serial number of component examined.

15.1.2 Size, material type and grade, and configuration of welds examined. If required by type of equipment chosen, thickness of coating and variation in coating thickness.

15.1.3 Weld numbering system.

15.1.4 Extent of examination, for example, areas of interest, complete or partial coverage, which welds, and to what length.

15.1.5 The names and qualifications of personnel performing the examination.

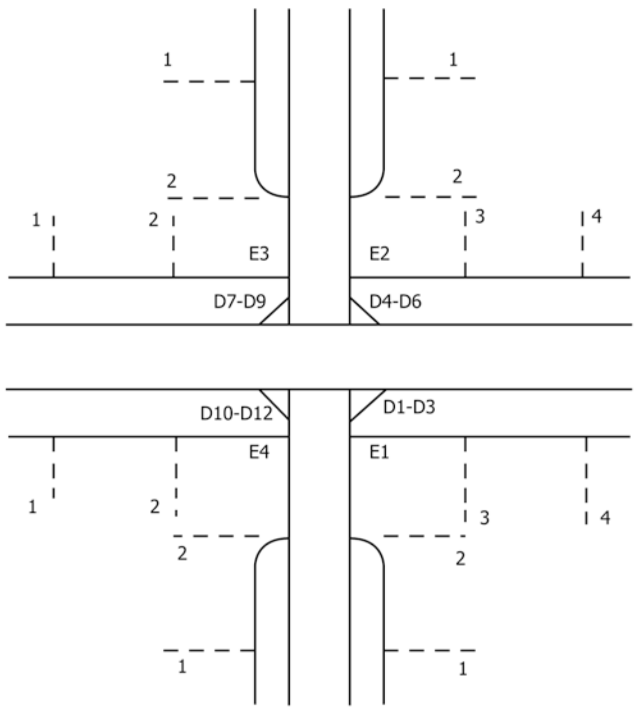


FIG. 10 Nomenclature for Vertical Welds

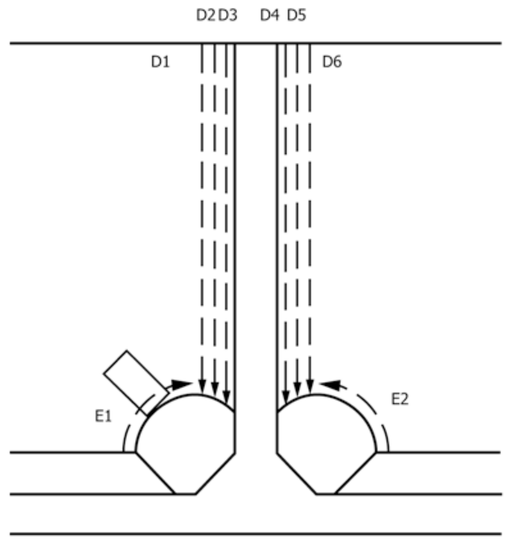


FIG. 11 Scans of Vertical Cut Out Weld and Cut Out Surface

15.1.6 Models, types, and serial numbers of the components of the alternating current field measurement system used, including all probes.

15.1.7 For the initial data acquisition from the operation reference standard, a complete list of all relevant instrument settings and parameters used, such as operating frequencies, and probe speed. The list shall enable settings to be referenced to each individual weld examined.

15.1.8 Serial numbers of all of the operations reference standards used.

15.1.9 Brief outline of all techniques used during the examination.

15.1.10 A list of all areas not examinable or where limited sensitivity was obtained. Indicate which discontinuities on the operations reference standard would not have been detectable in those regions. Where possible, indicate factors that may have limited sensitivity.

NOTE 3—Factors that influence sensitivity to discontinuities include but are not limited to: operating frequency, instrument noise, instrument filtering, digital sample rate, probe speed, coil configuration, probe travel noise and interference described in Section 8.

15.1.11 Specific information about techniques and depth sizing for each discontinuity.

15.1.12 Acceptance criteria used to evaluate discontinuities.

15.1.13 A list of discontinuities as specified in the purchasing agreement with the thickness of the coating over these discontinuities if the equipment does not measure and compensate for lift-off.

15.1.14 Complementary examination results that influenced interpretation and evaluation.

15.2 Record data and system settings in a manner that allows archiving and later recall of all data and system settings for each weld. Throughout the examination, data shall be permanently recorded, unless otherwise specified by the client.

15.2.1 *Report form.* An example report form is shown in Table 2.

16. Keywords

16.1 alternating current field measurement; electromagnetic examination; ferromagnetic weld; non-conducting material; weld

TABLE 1 Reporting Requirements

NOTE 1—The data report sheets generated by the alternating current field measurement examination will be specifically designed with the system and current examination requirements in mind. The essential information contained on a data sheet will include:

General Information
Date
Operators Name
Probe Operator
Component ID Number
File Number
Equipment Used

Scanning Data
Filename
Page Number
Position on Weld
Probe Number
Probe Direction
Tape Position
Examination Summary

Detailed Record of Indications / Anomalies
Filename
Page Number
Position on Weld
Start of Discontinuity (Tape reference)
End of Discontinuity (Tape reference)
Length of Discontinuity (inches/millimetres)
Thickness of Coating over Discontinuity (inches/millimetres, if required by equipment)
Remarks
Diagram/Drawing of component under examination

TABLE 2 Example Alternating Current Field Measurement Report Form

Date: Time:	Location:	Sketch of geometry:
Operator:	Probe Op:	
Component ID:		
Summary of discontinuities:		
Filename:		
Probe Number:		Probe File:

Distance from Datum	Direction of travel	Weld Position	Page	Examination report/ comments

ARTICLE 32
REMOTE FIELD TESTING STANDARD

STANDARD PRACTICE FOR IN SITU EXAMINATION OF FERROMAGNETIC HEAT-EXCHANGER TUBES USING REMOTE FIELD TESTING

(19) SE-2096/SE-2096M

(Identical with ASTM Specification E2096/E2096M-16.)

Standard Practice for In Situ Examination of Ferromagnetic Heat-Exchanger Tubes Using Remote Field Testing

1. Scope

1.1 This practice describes procedures to be followed during remote field examination of installed ferromagnetic heat-exchanger tubing for baseline and service-induced discontinuities.

1.2 This practice is intended for use on ferromagnetic tubes with outside diameters from 0.500 to 2.000 in. [12.70 to 50.80 mm], with wall thicknesses in the range from 0.028 to 0.134 in. [0.71 to 3.40 mm].

1.3 This practice does not establish tube acceptance criteria; the tube acceptance criteria must be specified by the using parties.

1.4 *Units*—The values stated in either inch-pound units or SI units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Other Documents:*

Can CGSB-48.9712-95 Qualification of Nondestructive Testing Personnel, Natural Resources Canada

ISO 9712 Nondestructive Testing—Qualification and Certification of Nondestructive Testing Personnel

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

3. Terminology

3.1 *General*—Definitions of terms used in this practice can be found in Terminology E1316, Section A, "Common NDT Terms," and Section C, "Electromagnetic Testing."

3.2 *Definitions:*

3.2.1 *detector, n*—one or more coils or elements used to sense or measure magnetic field; also known as a receiver.

3.2.2 *exciter, n*—a device that generates a time-varying electromagnetic field, usually a coil energized with alternating current (ac); also known as a transmitter.

3.2.3 *nominal tube, n*—a tube or tube section meeting the tubing manufacturer's specifications, with relevant properties typical of a tube being examined, used for reference in interpretation and evaluation.

3.2.4 *remote field, n— as applied to nondestructive testing*, the electromagnetic field which has been transmitted through the test object and is observable beyond the direct coupling field of the exciter.

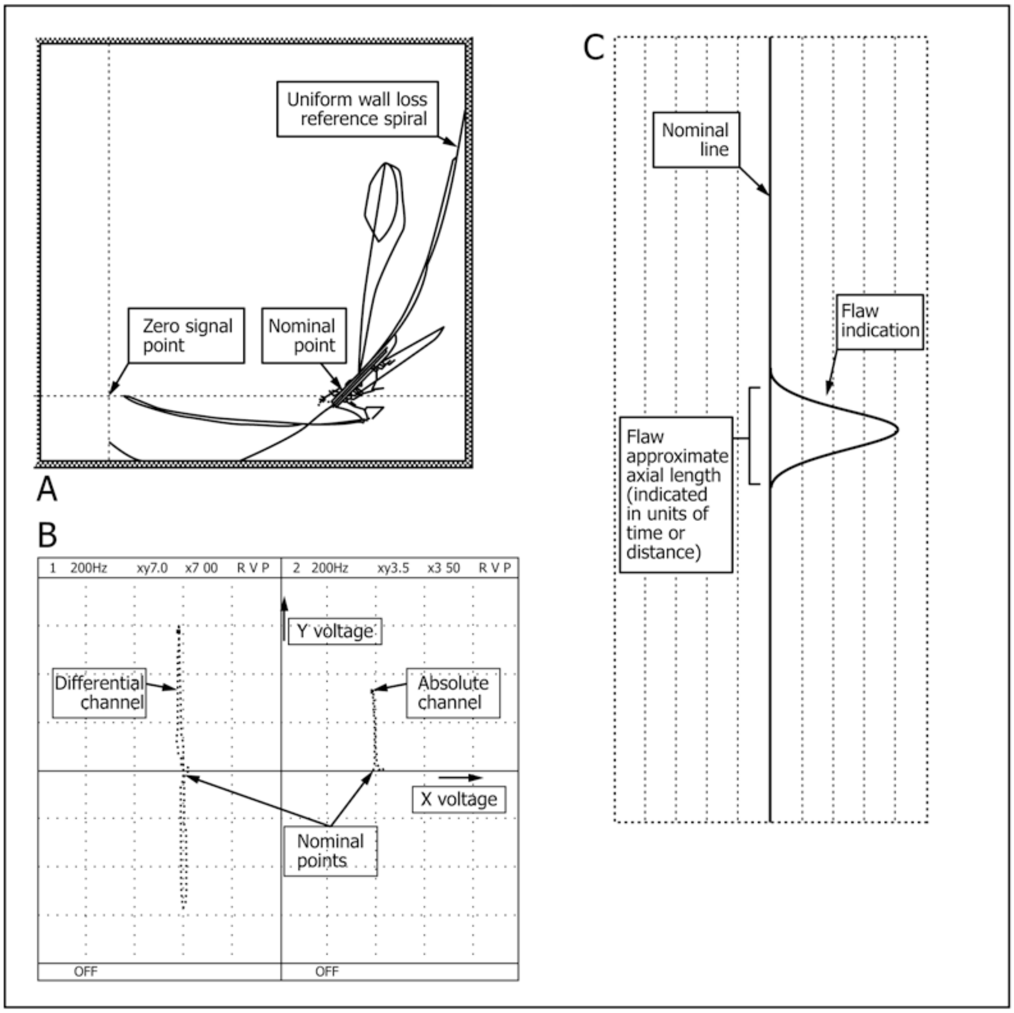


FIG. 1 A and B: Typical Phase-Amplitude Diagrams Used in RFT; C: Generic Strip Chart With Flaw

3.2.5 *remote field testing, n*—a nondestructive test method that measures changes in the remote field to detect and characterize discontinuities.

3.2.6 *using parties, n*—the supplier and purchaser.

3.2.6.1 *Discussion*—The party carrying out the examination is referred to as the "supplier," and the party requesting the examination is referred to as the "purchaser," as required in *Form and Style for ASTM Standards*, April 2004. In common usage outside this practice, these parties are often referred to as the "operator" and "customer," respectively.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *flaw characterization standard, n*—a standard used in addition to the RFT system reference standard, with artificial or service-induced flaws, used for flaw characterization.

3.3.2 *nominal point, n*—a point on the phase-amplitude diagram representing data from nominal tube.

3.3.3 *phase-amplitude diagram, n*—a two-dimensional representation of detector output voltage, with angle representing phase with respect to a reference signal, and radius representing amplitude (Fig. 1a and 1b).

3.3.3.1 *Discussion*—In this practice, care has been taken to use the term "phase angle" (and "phase") to refer to an angular equivalent of time displacement, as defined in Terminology E1316. When an angle is not necessarily representative of time, the general term "angle of an indication on the phase-amplitude diagram" is used.

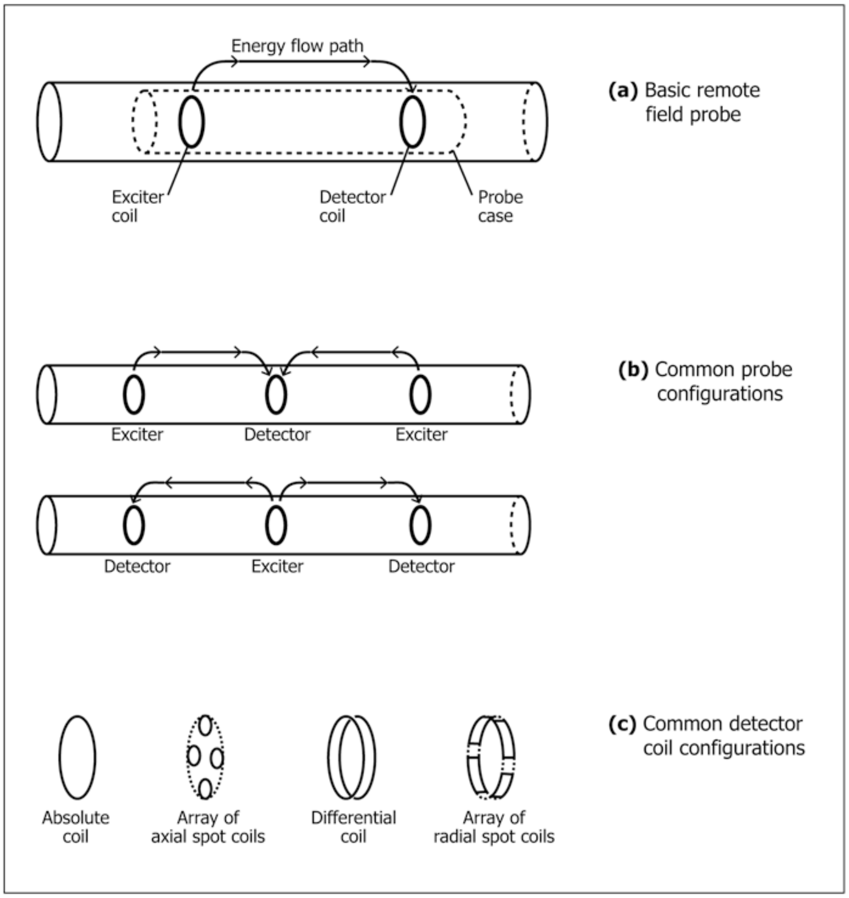
3.3.4 *RFT system, n*—the electronic instrumentation, probes, and all associated components and cables required for performing RFT.

3.3.5 *RFT system reference standard, n*—a reference standard with specified artificial flaws, used to set up and standardize a remote field system and to indicate flaw detection sensitivity.

3.3.6 *sample rate*—the rate at which data is digitized for display and recording, in data points per second.

3.3.7 *strip chart, n*—a diagram that plots coordinates extracted from points on a phase-amplitude diagram versus time or axial position (Fig. 1c).

3.3.8 *zero point, n*—a point on the phase-amplitude diagram representing zero detector output voltage.



NOTE 1—Arrows indicate flow of electromagnetic energy from exciter to detector. Energy flow is perpendicular to lines of magnetic flux.

FIG. 2 RFT Probes

3.3.8.1 *Discussion*—Data on the phase-amplitude diagram are plotted with respect to the zero point. The zero point is separate from the nominal point unless the detector is configured for zero output in nominal tube. The angle of a flaw indication is measured about the nominal point.

3.4 *Acronyms:*

3.4.1 *RFT, n*—remote field testing

4. Summary of Practice

4.1 The RFT data is collected by passing a probe through each tube. The electromagnetic field transmitted from the exciter to the detector is affected by discontinuities; by the dimensions and electromagnetic properties of the tube; and by objects in and around the tube that are ferromagnetic or conductive. System sensitivity is verified using the RFT system reference standard. System sensitivity and settings are checked and recorded prior to and at regular intervals during the examination. Data and system settings are recorded in a manner that allows archiving and later recall of all data and system settings for each tube. Interpretation and evaluation are carried out using one or more flaw characterization standards. The supplier generates a final report detailing the results of the examination.

5. Significance and Use

5.1 The purpose of RFT is to evaluate the condition of the tubing. The evaluation results may be used to assess the likelihood of tube failure during service, a task which is not covered by this practice.

5.2 *Principle of Probe Operation*—In a basic RFT probe, the electromagnetic field emitted by an exciter travels outwards through the tube wall, axially along the outside of tube, and back through the tube wall to a detector[1] (Fig. 2a).

5.2.1 Flaw indications are created when (*1*) in thin-walled areas, the field arrives at the detector with less attenuation and less time delay, (*2*) discontinuities interrupt the lines of magnetic flux, which are aligned mainly axially, or (*3*) discontinuities interrupt the eddy currents, which flow mainly circumferentially. A discontinuity at any point on the through-transmission path can create a perturbation; thus RFT has approximately equal sensitivity to flaws on the inner and outer walls of the tube.[1]

5.3 *Warning Against Errors in Interpretation.* Characterizing flaws by RFT may involve measuring changes from

[1] Schmidt, T. R., "The Remote Field Eddy Current Inspection Technique," *Materials Evaluation*, Vol. 42, No. 2, Feb. 1984, pp. 225-230.

nominal (or baseline), especially for absolute coil data. The choice of a nominal value is important and often requires judgment. Practitioners should exercise care to use for nominal reference a section of tube that is free of damage (see definition of "nominal tube" in 3.2.3). In particular, bends used as nominal reference must be free of damage, and tube support plates used as nominal reference should be free of metal loss in the plate and in adjacent tube material. If necessary, a complementary technique (as described in 11.12) may be used to verify the condition of areas used as nominal reference.

5.4 *Probe Configuration*—The detector is typically placed two to three tube diameters from the exciter, in a location where the remote field dominates the direct-coupling field.[7] Other probe configurations or designs may be used to optimize flaw detection, as described in 9.3.

5.5 *Comparison with Conventional Eddy-Current Testing*—Conventional eddy-current test coils are typically configured to sense the field from the tube wall in the immediate vicinity of the emitting element, whereas RFT probes are typically designed to detect changes in the remote field.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as specified in Practice E543, with reference to sections on electromagnetic testing. The applicable edition of Practice E543 shall be specified in the contractual agreement.

7. Job Scope and Requirements

7.1 The following items may require agreement between the using parties and should be specified in the purchase document or elsewhere:

7.1.1 Location and type of tube component to be examined, design specifications, degradation history, previous nondestructive examination results, maintenance history, process conditions, and specific types of flaws that are required to be detected, if known.

7.1.2 The maximum window of opportunity for work. (Detection of small flaws may require a slower probe pull speed, which will affect productivity.)

7.1.3 Size, material grade and type, and configuration of tubes to be examined.

7.1.4 A tube numbering or identification system.

7.1.5 Extent of examination, for example: complete or partial coverage, which tubes and to what length, whether straight sections only, and the minimum radius of bends that can be examined.

7.1.6 Means of access to tubes, and areas where access may be restricted.

7.1.7 Type of RFT instrument and probe; and description of reference standards used, including such details as dimensions and material.

7.1.8 Required operator qualifications and certification.

7.1.9 Required tube cleanliness.

7.1.10 Environmental conditions, equipment, and preparations that are the responsibility of the purchaser; common sources of noise that may interfere with the examination.

NOTE 1—Nearby welding activities may be a major source of interference.

7.1.11 Complementary methods or techniques (including possible tube removal) that may be used to obtain additional information.

7.1.12 Acceptance criteria to be used in evaluating flaw indications.

7.1.13 Disposition of examination records and reference standards.

7.1.14 Format and outline contents of the examination report.

8. Interferences

8.1 This section describes items and conditions which may compromise RFT.

8.2 *Material Properties:*

8.2.1 Variations in the material properties of ferromagnetic tubes are a potential source of inaccuracy. Impurities, segregation, manufacturing process, grain size, stress history, present stress patterns, temperature history, present temperature, magnetic history, and other factors will affect the electromagnetic response measured during RFT. The conductivity and permeability of tubes with the same grade of material are often measurably different. It is common to find that some of the tubes to be examined are newer tubes with different material properties.

8.2.2 Permeability variations may occur at locations where there was uneven temperature or stress during tube manufacture, near welds, at bends, where there were uneven heat transfer conditions during service, at areas where there is cold working (such as that created by an integral finning process), and in other locations. Indications from permeability variations may be mistaken for, or obscure flaw indications. Effects may be less severe in tubes that were stress-relieved during manufacture.

8.2.3 Residual stress, with accompanying permeability variations, may be present when discontinuities are machined into a reference standard, or during the integral finning process.

8.2.4 RFT is affected by residual magnetism in the tubing, including residual magnetism created during a previous examination using another magnetic method. Tubes with significant residual magnetism should be demagnetized prior to RFT.

8.3 *Ferromagnetic and Conductive Objects:*

8.3.1 Objects near the tube that are ferromagnetic or conductive may reduce the sensitivity and accuracy of flaw characterization in their immediate vicinity. Such objects may in some cases be mistaken for flaws. Knowledge of the mechanical layout of the component to be examined is recommended. Examples of ferromagnetic or conductive objects include: tube support plates, baffle plates, end plates, tube sheets, anti-vibration bars, neighboring tubes, impingement plates, loose parts, and attachments clamped or welded to a tube.

NOTE 2—Interference from ferromagnetic or conductive objects can be of practical use when RFT is used to confirm the position of an object installed on a tube or to detect where objects have become detached and have fallen against a tube.

8.3.2 *Neighboring Tubes:*

8.3.2.1 In areas where there is non-constant tube spacing (bowing) or where tubes cross close to each other, there are indications which may be mistaken for flaws.

8.3.2.2 Neighboring or adjacent tubes, in accordance with their number and position, create an offset in the phase. This phenomenon is known as the bundle effect and is a minor source of inaccuracy when absolute readings in nominal tube are required.

8.3.2.3 In cases where multiple RFT probes are used simultaneously in the same heat exchanger, care should be taken to ensure adequate spacing between different probes.

8.3.3 Conductive or magnetic debris in or on a tube that may create false indications or obscure flaw indications should be removed.

8.4 *Tube Geometry Effects:*

8.4.1 Due to geometrical effects (as well as to the effects of permeability variations described in 8.2.2), localized changes in tube diameter such as dents, bulges, expansions, and bends create indications which may obscure or distort flaw indications.

8.4.2 Reductions in the internal diameter may require a smaller diameter probe that is able to pass through the restriction. In the unrestricted sections, flaw sensitivity is likely to be limited by the smaller probe fill factor.

8.4.3 *RFT End Effect*—The field from the exciter is able to propagate around the end of a tube when there is no shielding from a tube sheet or vessel shell. A flaw indication may be obscured or distorted if the flaw or any active probe element is within approximately three tube diameters of the tube end.

8.5 *Instrumentation:*

8.5.1 The operator should be aware of indicators of noise, saturation, or signal distortion particular to the instrument being used. Special consideration should be given to the following concerns:

8.5.1.1 In a given tube, an RFT system has a frequency where the flaw sensitivity is as high as practical without undue influence from noise.

8.5.1.2 Saturation of electronic components is a potential problem in RFT because signal amplitude increases rapidly with decreasing tube wall thickness. Data acquired under saturation conditions is not acceptable.

8.5.2 *Instrument-induced Phase Offset*—During the amplification and filtering processes, instruments may introduce a frequency-dependent time delay which appears as a constant phase offset. The instrument phase offset may be a source of error when phase values measured at different frequencies are compared.

9. RFT System

9.1 *Instrumentation*—The electronic instrumentation shall be capable of creating exciter signals of one or more frequencies appropriate to the tube material. The apparatus shall be capable of phase and amplitude analysis of detector outputs at each frequency, independent of other frequencies in use simultaneously. The instrument shall display data in real time. The instrument shall be capable of recording data and system settings in a manner that allows archiving and later recall of all data and system settings for each tube.

9.2 *Driving Mechanism*—A mechanical means of traversing the probe through the tube at approximately constant speed may be used.

9.3 *Probes*—The probes should be of the largest diameter practical for the tubes being examined, leaving clearance for debris, dents, changes in tube diameter, and other obstructions. The probes should be of an appropriate configuration and size for the tube being examined and for the flaw type or types to be detected. Probe centering is recommended.

9.3.1 *Absolute Detectors*—Absolute detectors (Fig. 2c) are commonly used to characterize and locate large-volume and gradual metal loss.

9.3.2 *Differential Detectors*—Differential detectors (Fig. 2c) tend to maximize the response from small volume flaws and abrupt changes along the tube length, and are also commonly used to locate and characterize large-volume and gradual metal loss.

9.3.3 *Array Detector*—Array detectors use a configuration of multiple sensing elements (Fig. 2c). Each element is sensitive to a discrete section of the tube circumference. The elements may be oriented with their axes aligned axially or radially with respect to the tube.

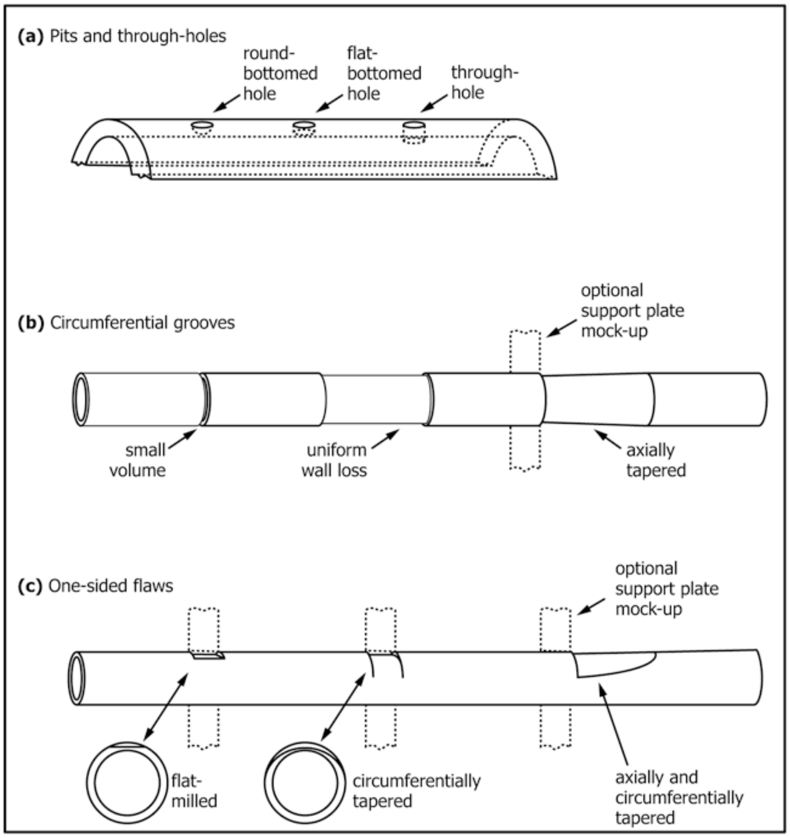
NOTE 3—The detector's response represents an average of responses to all flaws within its sensing area.

9.3.4 *Exciter and Detector Configurations*—Probes may have multiple exciters and detectors in a variety of configurations (see, for example, Fig. 2b). These configurations may reduce interference from support plates and other conductive objects.

9.4 *Data Displays:*

9.4.1 The data display should include a phase-amplitude diagram (Fig. 1a and 1b).

9.4.2 *Strip Charts*—Coordinates that may be displayed on strip charts include: horizontal position, vertical position, angular position, or radial position. Angular position may represent phase. Angular position and the logarithm of radial position for an absolute detector may be linearly related to overall wall thickness.



NOTE 1—Not to scale.

FIG. 3 Typical Artificial Discontinuities Used for Flaw Characterization Reference Standards

10. RFT Tube Standards

10.1 The RFT reference standards should be of the same nominal dimensions, material type, and grade as the tubes to be examined. In the case where a reference standard identical to the tubes to be examined is not available, a demonstration of examination equivalency is recommended. Subsection 11.6.2 specifies how to determine if a reference standard of different properties is appropriate for use.

10.2 The RFT system reference standard shall not be used for flaw characterization unless the artificial flaws can be demonstrated to be similar to the flaws detected.

10.3 *Typical Artificial Flaws in Flaw Characterization Standards:*

10.3.1 *Through, Round-Bottomed, and Flat-Bottomed Holes*—Holes of different depths are used for pit characterization, and may be machined individually or in groups. Drill and milling tools of different diameters can be used to produce different flaw volumes for a given depth of metal loss (Fig. 3a).

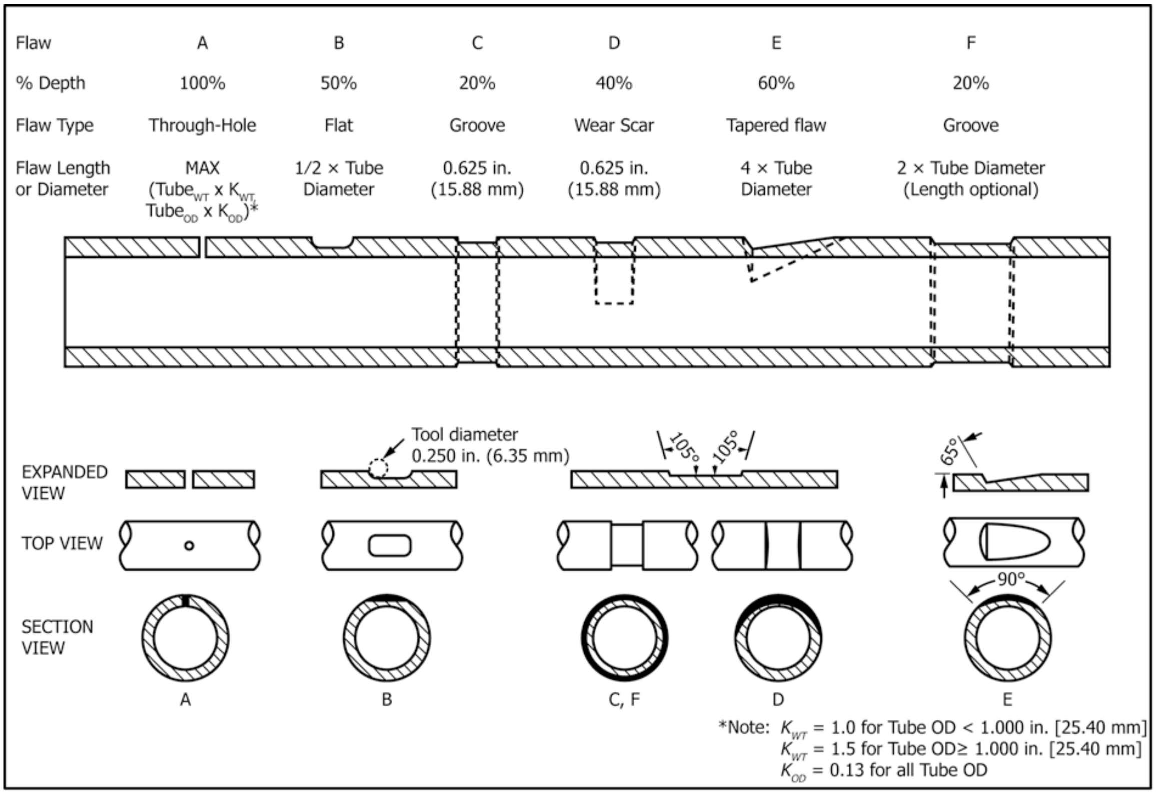
10.3.2 *Circumferential Grooves*—A circumferential groove is an area of metal loss whose depth at any axial location is uniform around the tube circumference. Short grooves, with a maximum axial length of less than one half a tube diameter, may be used to simulate small-volume metal loss. Grooves with an axial length of several tube diameters may be used to simulate uniform wall loss (Fig. 3b).

10.3.3 *One-Sided Flaws*—Metal loss is referred to as one-sided if it is predominantly on one side of a tube. Outside diameter long, flat flaws typically simulate tube-to-tube wear. Circumferentially tapered one-sided flaws typically simulate tube wear at support plates. Flaws tapered in both axial and circumferential directions typically simulate steam erosion adjacent to the tube support (Fig. 3c).

10.4 *RFT System Reference Standards*—Flaw depths are specified by giving the deepest point of the flaw as a percentage of the measured average wall thickness. Flaw depths shall be measured and accurate to within ±20 % of the depth specified or ±0.003 in. [±0.08 mm], whichever is smaller. All other flaw dimensions (such as length and diameter) shall be accurate to within ±0.010 in. [±0.25 mm] of the dimension specified. Angles shall be accurate to within ±5°.

10.5 *Artificial Flaws for RFT System Reference Standards:*

10.5.1 The RFT system reference standard has specific artificial flaws. It is used to set up and standardize a remote field system and to indicate flaw detection sensitivity. Unless otherwise specified by the purchaser, the artificial flaws for the RFT system reference standard are as follows:



NOTE 1—Not to scale. See 10.5 for tolerances and details.

FIG. 4 Manufacturing Reference for RFT System Reference Standard

10.5.1.1 *Through-Hole*—A through-hole (Fig. 4, Flaw A) whose diameter depends on the tube outside diameter and wall thickness in order to accommodate the natural reduction in sensitivity of absolute and differential detectors with increasing tube diameter. The through hole diameter is equal to the tube wall thickness multiplied by a specified factor (K_{WT}) or the tube outside diameter multiplied by a specific factor (K_{OD}), whichever is greater.

$$\text{Through-Hole}_{DIAM} = MAX(Tube_{WT} \times K_{WT},\ \ Tube_{OD} \times K_{OD}) \qquad (1)$$

where:

K_{WT} = 1 for $Tube_{OD}$ < 1.000 in. [25.40 mm],
K_{WT} = 1.5 for $Tube_{OD} \geq$ 1.000 in. [25.40 mm], and
K_{OD} = 0.13 for any $Tube_{OD}$ (which represents 15° of the tube circumference).

10.5.1.2 *Flat-Milled Flaw*—A flat-milled flaw (Fig. 4, Flaw B) of a depth of 50 % and axial length one half the tube nominal outside diameter. The flat should be side-milled using a milling tool of a diameter of 0.250 in. [6.35 mm] to create rounded corners.

10.5.1.3 *Short Circumferential Groove*—A short circumferential groove (Fig. 4, Flaw C) of a depth of 20 % and axial length of 0.625 in. [15.88 mm]. Edges shall be angled at 105° as indicated in the insert in Fig. 4.

10.5.1.4 *Wear Scar*—A simulated wear scar from a tube support plate (Fig. 4, Flaw D), consisting of a circumferentially tapered groove, 40 % deep, extending over 180° of the tube circumference. Axial length measured at the bottom surface of the flaw shall be 0.625 in. [15.88 mm]. Edges shall be angled at 105° as indicated in the insert in Fig. 4.

10.5.1.5 *Tapered Flaw*—A tapered flaw simulating near-tube-support erosion (Fig. 4, Flaw E) consisting of a groove, 60 % deep, tapered circumferentially, and in both directions axially. The steep side of the flaw shall be angled at 65° to the tube axis. The shallow side of the flaw shall be axially tapered so that it extends an axial distance of four tube diameters from the deepest point. The circumferential extent at the maximum point shall be 90°.

10.5.1.6 *Long Circumferential Groove*—A long circumferential groove (Fig. 4, Flaw F) of a depth of 20 % and recommended axial length of two tube diameters. Length is optional in accordance with application. Edges shall be angled at 105°, as indicated in the insert in Fig. 4.

10.6 *Simulated Support Structures:*

10.6.1 The RFT reference standards may have simulated support structures to represent heat exchanger bundle conditions.

10.6.2 *Support Plates*—Support plates may be simulated by drilling a single hole through a solid flat plate with a radial clearance on the tube of up to 0.015 in. [0.38 mm]. To prevent the field from propagating around the plate, the minimum distance from the edge of the tube hole to the edge of the plate should be greater than two tube diameters, unless a smaller dimension can be demonstrated to be adequate. For example, the simulated tube support plate for a 1-in. [25.4 mm] diameter tube should be at least a 5-in. [127.00-mm] square or a 5-in. [127.00-mm] diameter circle. The accuracy of the support plate simulation may be increased if the simulated plate is of the same thickness and material as the support plates in the component to be examined.

10.7 *Manufacture and Care of RFT Reference Standards:*

10.7.1 *Drawings*—For each RFT reference standard, there shall be a drawing that includes the as-built measured flaw dimensions, material type and grade, and the serial number of the actual RFT tube standard.

10.7.2 *Serial Number*—Each RFT reference standard shall be identified with a unique serial number and stored so that it can be obtained and used for reference when required.

10.7.3 *Flaw Spacing*—Artificial flaws should be positioned axially to avoid overlapping of indications and interference from end effects.

10.7.4 Machining personnel shall use proper machining practices to avoid excessive cold-working, over-heating, and undue stress and permeability variations.

10.7.5 Tubes should be stored and shipped so as to prevent mechanical damage.

11. Procedure

11.1 If necessary, clean the inside of the tubes to remove obstructions and heavy ferromagnetic or conductive debris.

11.2 *Instrument Settings:*

11.2.1 *Operating Frequency*—Using the appropriate RFT system reference standard, the procedures in 11.2.1.1 or 11.2.1.2 are intended to help the user select an operating frequency. Demonstrably equivalent methods may be used. If the RFT system is not capable of operating at the frequency described by this practice, the supplier shall declare to the purchaser that conditions of reduced sensitivity may exist.

11.2.1.1 Using the RFT system reference standard, and referring to the phase-amplitude diagram, set the frequency to obtain a difference of 50 to 120° between the angles of indication for the reference through-hole (Flaw A in Fig. 4) and a 20 % circumferential groove of a axial length of 0.125 in. [3.18 mm] (as permitted for Flaw F in Fig. 4).

11.2.1.2 If phase is measured and displayed, set the frequency so that a 20 % circumferential groove with an axial length of two tube diameters (as permitted for Flaw F in Fig. 4) creates a phase shift of between 18 and 22° in the absolute detector output with only the detector coil in the region of metal loss.

11.2.2 *Secondary Frequencies*—To detect and characterize some damage mechanisms, it may be necessary to use secondary frequencies to provide additional information.

11.2.3 *Pull Speed*—Determine a pull speed appropriate to the frequency, sample rate, and required sensitivity to flaws.

11.2.4 Set other instrument settings as appropriate to achieve the minimum required sensitivity to flaws.

Note 4—Factors which influence sensitivity to flaws include, but are not limited to: operating frequency, instrument noise, instrument filtering, digital sample rate, probe speed, coil configuration, fill factor, probe travel noise, and interferences described in Section 8.

11.3 Ensure that the system yields the minimum required sensitivity to all flaws on the RFT system reference standard at the examination pull speed. For a flaw to be considered detectable, its indication should exceed the ambient noise by a factor of at least 3, unless otherwise specified by the purchaser. An exception may be made when the purchaser requires only a large-volume metal loss examination, in which case, sensitivity should be demonstrated for specified large-volume flaws on the RFT system reference standard.

11.4 Acquire and record data from the RFT system reference standard and flaw characterization standards at the selected examination pull speed.

11.5 Acquire and record data from the tubes to be examined. Maintain as uniform a probe speed as possible throughout the examination to produce repeatable indications.

11.5.1 Record data and system settings in a manner that allows archiving and later recall of all data and system settings for each tube. Throughout the examination, data shall be permanently recorded, unless otherwise specified by the purchaser.

11.5.2 For maintaining system consistency throughout the examination, monitor typical RFT responses from support plates and tube ends, or monitor the absolute phase in the nominal tube. If conditions change, appropriate adjustments need to be made in accordance with 11.6.

11.6 *Compensation for Material and Dimensional Differences:*

11.6.1 To compensate for differences in dimensional and material properties, the system may be re-normalized where appropriate by adjusting frequency or gain, or both. To re-normalize, adjust the settings so that one of the following values remains equal in the reference standard and in a nominal examined tube:

11.6.1.1 The amplitude and angular position of a support plate indication on the phase-amplitude diagram, or

11.6.1.2 The angular difference between a support plate indication and the tube-exit indication on the phase-amplitude diagram, or

11.6.1.3 The absolute phase in the nominal tube.

Note 5—For an alternate method of compensating for differences in dimensional and material properties, see 11.12.

11.6.2 The frequencies used in the reference standards and in the tubes to be examined should not differ by more than a factor of two. If the factor exceeds this value, the reference standard should be considered inappropriate and replaced with one that more accurately represents the material to be tested.

11.6.3 After frequency and gain adjustments have been made, apply appropriate compensations to the examination sample rate and pull speed.

11.7 *Compensation for Ferromagnetic or Conductive Objects:*

11.7.1 Techniques that may improve RFT results near interfering ferromagnetic or conductive objects include:

11.7.1.1 Comparison of baseline or previous examination data with the current examination data.

11.7.1.2 Comparison of indications from known objects with and without metal loss. (Obtain a reference indication from a typical object on or near the nominal tube or from a simulated object on a reference standard.)

11.7.1.3 The use of special probe coil configurations.

11.7.1.4 Processing of multiple-frequency signals to suppress irrelevant indications.

11.7.1.5 The use of a complementary method or technique (see 11.12).

11.8 *System Check*—At regular intervals, carry out a system check using the RFT system reference standard to demonstrate system sensitivity and operating parameters to the satisfaction of the purchaser. Carry out a system check prior to starting the examination, after any field compensation adjustments in accordance with 11.6, at the beginning and end of each work shift, when equipment function is in doubt, after a change of personnel, after a change of any essential system components, and overall at a minimum of every four hours. If the flaw responses from the RFT system reference standard have changed substantially, the tubes examined since the last system check shall be reexamined.

11.9 Interpret the data (identify indications).

11.10 Note areas of limited sensitivity, using indications from the RFT system reference standard as an indicator of flaw detectability.

11.11 Using a flaw characterization standard, evaluate relevant indications in accordance with acceptance criteria specified by the purchaser.

11.11.1 A common parameter used as a flaw depth indicator is the angle of an indication on the phase-amplitude diagram. Different angle-depth standardization curves may be used in accordance with flaw volume, as indicated by the amplitude of the indication on the phase-amplitude diagram.

11.12 If desired, examine selected areas using an appropriate complementary method or technique to obtain more information, adjusting results where appropriate.

11.13 Compile and present a report to the purchaser.

12. Report

12.1 The following items may be included in the examination report. All the following information should be archived, whether or not it is required in the report.

12.1.1 Owner, location, type, and serial number of component examined.

12.1.2 Size, material type and grade, and configuration of tubes examined.

12.1.3 Tube numbering system.

12.1.4 Extent of examination, for example, areas of interest, complete or partial coverage, which tubes, and to what length.

12.1.5 Personnel performing the examination and their qualifications.

12.1.6 Models, types, and serial numbers of the components of the RFT system used, including probe and extension length.

12.1.7 For the initial data acquisition from the RFT system reference standard, a complete list of all relevant instrument settings and parameters used, such as operating frequencies, probe drive voltages, gains, types of mixed or processed channels, and probe speed. The list shall enable settings to be referenced to each individual tube examined.

12.1.8 Serial numbers of all of the tube standards used.

12.1.9 Brief outline of all techniques used during the examination.

12.1.10 A list of all heat-exchanger regions or specific tubes where limited sensitivity was obtained. Indicate which flaws on the system reference standard would not have been detectable in those regions. Where possible, indicate factors that may have limited sensitivity.

12.1.11 Specific information about techniques and depth reference curves used for sizing each indication.

12.1.12 Acceptance criteria used to evaluate indications.

12.1.13 A list of flaws as specified in the purchasing agreement.

12.1.14 Complementary examination results that influenced interpretation and evaluation.

13. Keywords

13.1 eddy current; electromagnetic testing; ferromagnetic tube; remote field testing; RFT; tube; tubular products

ARTICLE 33
GUIDED WAVE STANDARDS

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STANDARD PRACTICE FOR GUIDED WAVE TESTING OF ABOVE GROUND STEEL PIPEWORK USING PIEZOELECTRIC EFFECT TRANSDUCTION

SE-2775

(Identical with ASTM Specification E2775-11.)

Standard Practice for Guided Wave Testing of Above Ground Steel Pipework Using Piezoelectric Effect Transduction

1. Scope

1.1 This practice provides a procedure for the use of guided wave testing (GWT), also previously known as long range ultrasonic testing (LRUT) or guided wave ultrasonic testing (GWUT).

1.2 GWT utilizes ultrasonic guided waves, sent in the axial direction of the pipe, to non-destructively test pipes for defects or other features by detecting changes in the cross-section and/or stiffness of the pipe.

1.3 GWT is a screening tool. The method does not provide a direct measurement of wall thickness or the exact dimensions of defects/defected area; an estimate of the defect severity however can be provided.

1.4 This practice is intended for use with tubular carbon steel or low-alloy steel products having Nominal Pipe size (NPS) 2 to 48 corresponding to 60.3 to 1219.2 mm (2.375 to 48 in.) outer diameter, and wall thickness between 3.81 and 25.4 mm (0.15 and 1 in.).

1.5 This practice covers GWT using piezoelectric transduction technology.

1.6 This practice only applies to GWT of basic pipe configuration. This includes pipes that are straight, constructed of a single pipe size and schedules, fully accessible at the test location, jointed by girth welds, supported by simple contact supports and free of internal, or external coatings, or both; the pipe may be insulated or painted.

1.7 This practice provides a general procedure for performing the examination and identifying various aspects of particular importance to ensure valid results, but actual interpretation of the data is excluded.

1.8 This practice does not establish an acceptance criterion. Specific acceptance criteria shall be specified in the contractual agreement by the responsible system user or engineering entity.

1.9 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

E1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *circumferential extent*—the length of a pipe feature in the circumferential direction, usually given as a percentage of the pipe circumference.

3.1.2 *coherent noise*—indications caused by real discontinuities causing a background noise, which exponentially decays with distance.

3.1.3 *Cross-Sectional Area Change (CSC)*—the CSC is calculated assuming that a reflection is purely caused by a change in cross-section. It is given as a percentage of the total cross-section. However it is commonly used to report the relative amplitude of any signal regardless of its source.

3.1.4 *Distance Amplitude Correction (DAC) curve*—a reference curve plotted using reference reflections (for example, weld reflections) at different distances from the test position.

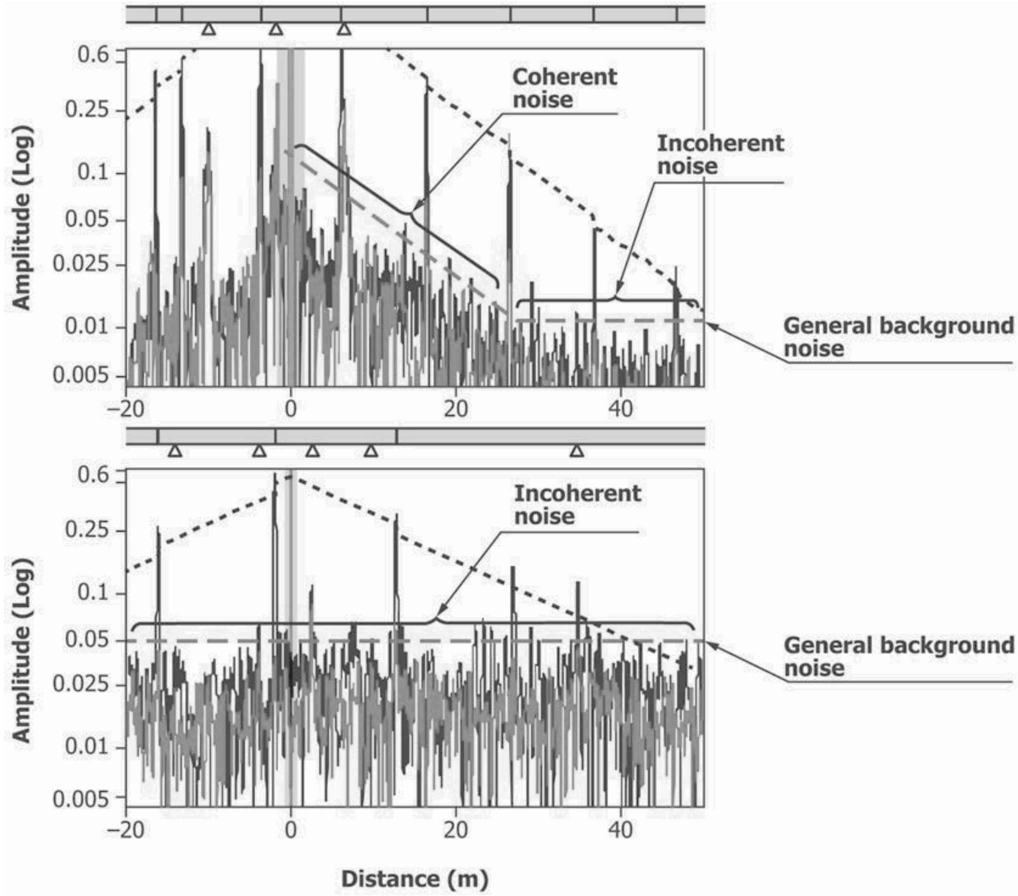

FIG. 1 Typical GWT Results Collected in Normal Environment (Top) and in High Ambient Noise Environment (Bottom). (Both results are displayed in the logarithmic amplitude scale.)

This curve corrects for attenuation and amplitude drops when estimating the cross-section change from a reflection at a certain distance.

3.1.5 *Estimated Cross Sectional Loss (ECL)*—this is sometimes used instead of Cross-Sectional Area Change, where the feature is related to a defect.

3.1.6 *flexural wave*—wave propagation mode that produces bending motion in the pipe.

3.1.7 *Guided Wave (GW)*—stress waves whose characteristics are constrained by the system material, geometry and configuration in which the waves are propagating.

3.1.8 *Guided Wave Testing (GWT)*—non-destructive test method that utilizes guided waves.

3.1.9 *longitudinal wave*—wave propagation mode that produces compressional motion in the pipe.

3.1.10 *incoherent noise*—random indications caused by electrical and ambient signal pollution, giving rise to a constant average noise floor. The terms "ambient noise" and "random noise" are also used.

3.1.11 *pipe feature* —pipe components including but not limited to weld, support, flange, bend and flaw (defect) cause reflections of a guided wave due to a change in geometry.

3.1.12 *reflection amplitude*—the amplitude of the reflection signal typically reported as CSC.

3.1.13 *reflector orientation*—the circumferential position of the feature on the pipe. This is reported as the clock position or degrees with regards to the orientation of the transducer ring.

3.1.14 *Signal to Noise Ratio (SNR)*—Ratio of the amplitude of any signal of interest to the amplitude of the average background noise which includes both coherent and non-coherent types of noise as defined in Fig. 1.

3.1.15 *torsional wave*—wave propagation mode that produces twisting motion in the pipe.

3.1.16 *transducer ring*—a ring array of transducers that is attached around the circumference of the pipe to generate GW. It is also commonly known as the Ring.

3.1.17 *wave mode*—a particular form of propagating wave motion generated into a pipe, such as flexural, torsional or longitudinal.

4. Summary of Practice

4.1 GWT evaluates the condition of metal pipes to primarily establish the severity classification of defects by applying GW at a typical test frequency of up to 150 kHz, which travels along the pipe. Reflections are generated by the change in cross-sectional area and/or local stiffness of the pipe.

4.2 A transducer ring attached around the pipe screens the pipe in both directions simultaneously. It can evaluate long lengths of pipe, and is especially useful when access to the pipe is limited.

4.3 This examination locates areas of thickness reduction(s) and provides a severity classification as to the extent of that damage. The results are used to assess the condition of the pipe, to determine where damaged areas are located and their circumferential position on the pipe. The information can be used to program and prioritize additional inspection work and repairs.

4.4 Reflections produced by pipe features that are not associated with areas containing possible defects are considered as relevant signals. These features can be used for setting GW system DAC levels and identifying the relative position and distance of discontinuities and areas containing possible defects. Examples of these features are: circumferential welds, elbows, welded supports, vents, drainage, insulation lugs and other welded attachments.

4.5 Other sources of reflection may include changes in surface impedance of the pipe. These reflections are normally not relevant, but should be analyzed and classified in an interpretation process. Examples of these changes are presence of pipe supports and clamps. In the advanced applications which are not covered by this practice, these changes may also include various types of external/internal coatings, entrance of the pipe to ground or concrete wall.

4.6 Inspection of the pipe section immediately connecting to branch connections, bends or flanges are considered advance applications which are not covered by this practice.

4.7 False echoes are produced by phenomena such as reverberations, incomplete control of direction, distortion at elbows and others. These signals should be analyzed and classified as false echoes in the interpretation process.

5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for using GWT to locate areas in metal pipes in which wall loss has occurred due to corrosion or erosion.

5.2 GWT does not provide a direct measurement of wall thickness, but is sensitive to a combination of the CSC and circumferential extent and axial extent of any metal loss. Based on this information, a classification of the severity can be assigned.

5.3 The GWT method provides a screening tool to quickly identify any discontinuity along the pipe. Where a possible defect is found, follow-up inspection of suspected areas with ultrasonic testing or other NDT methods is normally required to obtain detailed thickness information, nature and extent of damage.

5.4 GWT also provides some information on the axial length of a discontinuity, provided that the axial length is longer than roughly a quarter of the wavelength.

5.5 The identification and severity assessment of any possible defects is qualitative only. An interpretation process to differentiate between relevant and non-relevant signals is necessary.

5.6 This practice only covers the application specified in the scope. The GWT method has the capability and can be used for applications where the pipe is insulated, buried, in road crossings and where access is limited.

5.7 GWT shall be performed by qualified and certified personnel, as specified in the contract or purchase order. Qualifications shall include training specific to the use of the equipment employed, interpretation of the test results and guided wave technology.

5.8 A documented program which includes training, examination and experience for the GWT personnel certification shall be maintained by the supplying party.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

6.2 *Personnel Qualifications*—Unless otherwise specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with one of the following:

6.2.1 Personnel performing examinations to this practice shall be qualified in accordance with SNT-TC-1A and certified by the employer or certifying agency, as applicable. Other equivalent qualification documents may be used when specified in the contract or purchase order. The applicable revision shall be the latest unless otherwise specified in the contractual agreement between parties.

6.2.2 Personnel qualification accredited by the GWT manufacturers.

6.3 This practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.4 *Qualifications of Non-destructive Testing Agencies*—Unless otherwise specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in E543, the applicable edition of E543 shall be specified in the contractual agreement.

6.5 *Procedure and Techniques*—The procedures and techniques to be utilized shall be specified in the contractual agreement. It should include the scope of the inspection, that is, the overall NDT examination intended to identify and estimate the size of any indications detected by the examination, or simply locate and provide a relative severity classification.

6.6 *Surface Preparation*—The pre-examination site preparation criteria shall be in accordance with 8.3 unless otherwise specified.

6.7 *Required Interval of Examination*—The required interval or the system time in service of the examination shall be specified in the contractual agreement.

6.8 *Extent of the Examination*—The extent of the examination shall be in accordance with 6.5 above unless otherwise specified. The extent should include but is not limited to:

6.8.1 The sizes and length(s) of pipes to be inspected.

6.8.2 Limitations of the method in the areas of application.

6.8.3 Drawings of pipe circuits, pipe nomenclature and identification of examination locations.

6.8.4 Pipe access method(s).

6.8.5 Safety requirements.

6.9 *Reporting Criteria*—The test results of the examination shall be documented in accordance with the contractual agreement. This may include requirements for permanent records of the collected data and test reports. The report documentation should include:

6.9.1 Equipment inspector and test results reviewed by (if applicable).

6.9.2 Date and time of the examination performed.

6.9.3 Equipment used.

6.9.4 Test procedure/specification used.

6.9.5 Acceptance criteria.

6.9.6 Inspection location.

6.9.7 Identification of areas inspected.

6.9.8 Identification of the inspection range.

6.9.9 Any other information deemed necessary to reproduce or duplicate test results.

6.10 *Re-examination of Repairs/Rework Items*—Examination of repaired/reworked items is not addressed in this practice and if required shall be specified in the contractual agreement.

7. Apparatus

7.1 The GWT apparatus shall include the following:

7.1.1 *Transducer Ring Transmitter*—A transduction system using piezoelectric effect for the generation of guided wave modes with axial propagation on cylindrical pipes.

7.1.2 *Transducer Ring Receiver*—A system for the detection of the signal reflected by the geometric features on the pipe, which can be the same as the transmitter or an analogous transduction system.

7.1.3 *Instrumentation*—The GWT instrumentation shall be capable of generating, receiving and amplifying electrical pulses within the frequency range used by GWT. Additionally, it shall be capable of communicating with a computer so that collected data can be processed and recorded.

7.1.4 *Processing System*—This is a software interface for processing and analyzing the signal, capable of distinguishing at least one guided wave mode for the specific detection system.

8. Examination Procedure

8.1 It is important to ensure that the proposed inspection falls within the capabilities of the technology and equipment and that the using party or parties understand the capabilities and limitations as it applies to their inspection.

8.2 *Pre-examination Preparation:*

8.2.1 All test equipment shall have current and valid calibration certificates.

8.2.2 Follow the equipment manufacturer's recommendations with regard to equipment pre-test verification and check list. As a minimum this check list should include but is not limited to:

8.2.2.1 Electronics fully operational.

8.2.2.2 Proper charging of batteries.

8.2.2.3 Verification that interconnection cables are in good condition and functioning correctly.

8.2.2.4 Correct transducer ring size for the intended pipes.

8.2.2.5 Sufficient transducer modules (including spares) are available to test the largest diameter pipe in the work scope.

8.2.2.6 The transducer ring, modules and transducers are functioning correctly.

8.2.2.7 Any computer used with the system is functioning correctly and has sufficient storage capacity for the intended work scope.

8.2.2.8 Supplementary equipment, such as an ultrasonic flaw detector or specialized pit gauges are available and functioning correctly.

8.2.2.9 All necessary accessories such as tape-measure, markers are available.

8.2.3 Ensure all site safety requirements and procedures are reviewed and understood prior to starting any field work.

8.3 *Examination Site Preparation:*

8.3.1 *Pipe Surface Condition*—To obtain best coupling condition, any loose material such as mud, flaking paint and loose corrosion must be removed from the surface of the pipe where the transducer ring is attached. However well-bonded paint layers of up to 1 mm (0.04 in.) can stay in place. Wire brushing and/or sanding are usually sufficient to prepare the surface if it is safe and permitted to do so.

8.3.2 *Insulation*—If the pipe is insulated, carefully remove approximately 1 m (3 ft) band of insulation for attaching the transducer ring. Prior to removing the insulating material ensure it is safe and permissible to do so.

8.3.3 GWT is most effective for testing long lengths of pipe. However tight radius elbows distort GWT signals, making interpretation of signal beyond them difficult. Where possible, it is good practice to exclude from evaluation, sections of pipe immediately after elbows. In any case, no signals after two elbows should be analyzed. It is sometimes better to take additional data at different locations than interpreting a signal beyond multiple features or those with complicated geometries. Consider taking a second reading 1 m (3 ft) apart for confirmation of features and false echo identification.

8.3.4 *Visual Inspection*—Visually inspect the pipe where possible for potential damage areas or corrosion, such as the support areas if possible defect indications are found in the GWT result.

8.3.5 *Surface Temperature*—Verify that the surface temperature of the pipe to be tested is within the manufacturer's specifications for the equipment. Testing at elevated temperatures does not in general affect the performance of the GWT, however caution must be exercised to avoid injuries to personnel. When testing low temperature pipes, ensure that no ice forms between the sensor face and the surface of the pipe.

8.3.6 *Thickness Check*—Before mounting the transducer ring, verify that there is no degradation in the pipe wall thickness at the test location. As a minimum requirement, thickness measurements at no less than four equally spaced positions around the pipe should be made using an appropriate thickness measuring instrument and procedure. Some agencies also require thickness measurement of the entire dead zone and near field. It is important to note that attaching the transducer ring at locations with very severe corrosion may cause further damage to the pipe.

8.4 *Transducer Ring*—The type of ring, the transducer orientation and their spacing can vary depending on the type of collection protocol. Refer to 8.13 when selecting the transducer ring assembly for the type of examination to be performed.

8.5 *Couplant*—Couplant is generally not required for this method. GWT utilizes relatively low frequency compared to those used in conventional UT, typically in the regions of tens of kilohertz (kHz) as opposed to megahertz (MHz). At these frequencies, good coupling is obtained by simply applying sufficient mechanical force on the transducer ring.

8.6 *Choosing Test Location*—After completing the examination site preparation outlined in 8.3, attach the transducer ring to the pipe. The test location should be chosen so as to minimize false echoes. Avoid placing the ring near a feature as the corresponding signal may appear within the near field or the dead zone. In the dead zone, no echoes are received, and in the near field, the amplitude of the echoes is typically lower than normal. As a practice, a minimum of 1.5 m (5 ft) should be used to the first area of inspection. Features such as welds which are used for the DAC curves fitting, should be outside the near field to ensure valid amplitude. Additionally, transducer rings should not be positioned equidistant between two features to avoid masking of the mirror echoes if any.

8.7 *Attaching the Transducer Ring*—When attaching the transducer ring it is important to ensure that all transducers are in good contact with the pipe and that the ring is mounted parallel to the circumference of the pipe. Applies the appropriate air pressure or clamp torque settings as specified in the manufacturer's operating manual for proper installation of the transducer ring.

8.8 *Directionality and Orientation*—The reported directionality and orientation of the features depend on the way the transducer ring is installed. It is good practice to keep the direction between different test positions the same, and in the direction of product flow if known. To ensure the correct orientation is reported, the transducer ring should be attached with the correct ring attachment configurations.

8.9 *Reproducibility*—The examination pipe should be marked with a paint marker indicating the transducer ring position, direction and date of examination. This can assist, should it be necessary to reproduce the examination in the future. This information should also be included in the examination documentation.

8.10 *Test location Information*—As the data collections of most GWT equipments are fully recorded electronically, a minimum amount of information about the test location is needed in the processing software to ensure the exact location can be identified. This information shall include the following:

8.10.1 *Site Name*—The name of the site, which may include the plant name, plant unit number, approximate mile marker or any relevant reference if available.

8.10.2 *Pipe*—The pipe identification if available, if not the pipe diameter should be recorded.

8.10.3 *Datum*—The reference feature from which the test location is measured. Typical reference features used are welds and flanges.

8.10.4 *Distance*—The distance between the datum and the center of the transducer ring shall be recorded. It is also important to include both positive and negative signs in front of the distance value for positive and negative direction of the ring respectively.

8.11 *Coupling Check*—It is important that all transducers are well coupled to the pipe. Prior to collecting any test data, perform a coupling test in accordance with the manufacturer's guidelines. As a minimum, this shall include a way of simulating "signals" on the pipe and verifying that all transducers detect it with a similar magnitude and sensitivity.

8.12 *Examination Precautions*—There are several precautions that need to be addressed when analyzing the collected data. These include:

8.12.1 *Dead Zone*—This is an area that can be up to 1 m (3 ft) long on either side of the transducer ring that is not inspected during the testing. The area of the dead zone is a function of the excitation frequency and the number of cycles transmitted. The area is inversely related to frequency and directly related to the number of cycles. In order to get a 100 % coverage of the pipe there are two options:

8.12.1.1 Inspection the dead zone with an alternative NDT method such as ultrasonic testing.

8.12.1.2 Locate the next shot so that there is overlap of the previous transducer ring position. Some agencies require a 20% overlap on all shots where possible.

8.12.2 *Near Field*—This is an area that could extend to as far as 3 m (10 ft) on either side of the transducer ring. In this area, the amplitudes are artificially lower than normal, and mirrors (see Section 8.20.4.1) can appear, making analysis of reflections in this area difficult. While this area is inspectable, extreme care must be taken when reviewing signals in this area. The length of this area depends on the length of excitation signal. It is possible to reduce the extent of the near field effect by employing special collection protocols.

8.12.3 *Expected Examination Range*—There are several physical test conditions on or around the pipe which affect the maximum examination range that can be achieved (see Appendix X1 for more detail). There are also equipment parameters such as frequency and gain settings, which can be varied so as to optimize the test parameters for specific test conditions on or around the pipe. The maximum inspection range is defined in 8.18.

8.12.4 *False Echo (False signals)*—Signals other than from a real feature. Care should be taken to minimize the potential for false signals to interfere with the interpretation of the data. The most common sources of false echoes are:

8.12.4.1 *Reverberations*—Multiple reflections either between two large features along the pipe, or between the two ends of a long feature. Echoes caused by reverberations typically have small amplitudes.

8.12.4.2 *Mirrors*—Occurs normally in the near field due to insufficient control of the propagation direction of the guided wave. The mirror echo appears at the same distance from transducer ring, but the opposite direction, as the real reflection.

8.12.4.3 *Modal Noise*—Occurs when the transducer ring is unable to control all the wave modes propagating in the pipe.

8.13 *Collection Protocol*—The collection protocol varies certain collection parameters to optimize the data quality based on the pipe diameter and the expected mechanism(s) on and around the pipe. Most manufacturers include a procedure for determining the optimum collection parameters automatically for a specific test condition. These collection parameters include:

8.13.1 *Frequency*—GWT is typically performed at frequencies between 10 and 150 kHz. When performing a test, data should be collected with enough different frequencies so as to be able to categorize each indication. Ideally, frequency can be changed quasi-continuously to observe frequency dependence, or if this is not available in the instrument multiple different frequencies including the optimum frequency should be collected. It is worth noting that the exact frequencies used vary depending on the pipe geometry.

8.13.2 *Bandwidth*—Changing the signal bandwidth can assist in resolving the attributes of a signal. A narrow bandwidth enhances the frequency dependency of a signal while a wider frequency bandwidth can improve the axial resolution of signals such as closely spaced reflections.

8.13.3 *Wave Mode*—The GWT uses an axi-symmetric wave mode excitation which can either be a torsional or longitudinal wave mode. Both wave modes provide valid inspection results. However in practice, torsional mode is commonly used as it is sensitive to most defect types. Nevertheless it is sometimes advantageous to use longitudinal mode over torsional mode if certain special defect types, such as corrosion at the axially welded supports, is known to be present on the pipe.

8.14 *Data Collection*—After installing the transducer ring and performing the coupling check, the next step of the examination procedure is data collection. It is important that the data recorded is sufficient and comprehensive to evaluate and interpret any signals which maybe present on the pipes. Choose the most appropriate collection protocol (see 8.13) and collection range to perform the initial data collection as per the equipment manufacturer's guidelines. Immediately afterward the data collection, it is important to review the collected data to ensure proper operation of the equipment during the test and the quality meets the required standard. The data review should include an evaluation of the SNR and the transducer balance. Poor SNR is usually caused by high incoherent noise, low transducer coupling or low transducer output. Should there be any significant problems observed in the data, it should be discarded and the problem addressed.

8.15 *Distance Amplitude Correction (DAC)*—As the excitation signal travels away from the transducer ring, its signal amplitude decreases. There are several reasons for the energy loss, including material damping, reflections at features, energy leakage and surface conditions. The DAC provides the ability to determine the signal amplitude at a point away from the transducer ring. This allows for determining the relative amplitude of an echo, expressed in either CSC or ECL, at a given distance. If the DAC curves are set too low, the size of possible defects may be overestimated, and vice versa. Therefore it is vital that the DAC levels are set correctly before interpreting the data as they provide reference CSC levels to all other signals for comparison. There are four DAC curves that can be used in evaluating GWT reflections. Most systems provide inspectors the means of manually adjusting these curves.

8.15.1 *Flange DAC*—This is a DAC curve that represents the expected amplitude of a reflection from a large feature which reflects approximately a 100 % (that is, 0dB) of the amplitude of the excitation signal and no energy can therefore pass through.

8.15.2 *Weld DAC*—Pipe girth welds typically present 20 % to 25 % CSC. The amount of energy reflected at the weld is the reason why the maximum number of pipe joints that can be inspected is limited.

8.15.3 *Call DAC*—This is the typical threshold level that is used to determine the severity of a defect if found. Most systems set the Call DAC level to roughly 6 % CSC by default, but also allow this level to be modified in accordance with the detection sensitivity requirement of the industry.

8.16 *Ambient Noise*—Ambient noise causes an increase in the overall incoherent noise level. In Fig. 1, the effect of an increased ambient noise is demonstrated, as both the detection sensitivity and the maximum inspection range are reduced as a result. Special precautions should be taken when ambient noise is higher than normal. Most equipment manufacturers offer special protocols to test in high ambient noise areas.

8.17 *Detection Threshold (DT)*—The DT of an examination is equivalent to the sensitivity, and it is typically set to 6 dB above the background noise but it can also be manually set by the inspectors.

8.18 *Inspection Range*—The section of pipe between the transducer ring and the end of test in one direction where the sensitivity is greater than the Call level (see 8.15.3). Depending on the coverage requirements, this inspection range is often used to determine the subsequent test locations. As the attenuation varies with frequency; the inspection range is normally specified for a particular frequency. The inspection range is also limited to a flange, or any feature that is not within the scope of the standard. (See also Fig. 2.)

8.19 *Distance Standardization*—The acoustic properties of different grades of steel varies slightly, causing an offset in the reported distance of the features. The software typically uses the acoustic properties of carbon steel. In most cases, the distance offset is very small and therefore it is not necessary to perform distance standardization. However, where the pipe material is not carbon steel, it is good practice to standardize distance in the software against a physical measurement prior to analyzing the data.

8.20 *Data Review*—The initial review of the data is to separate data into relevant, non-relevant signals and indications.

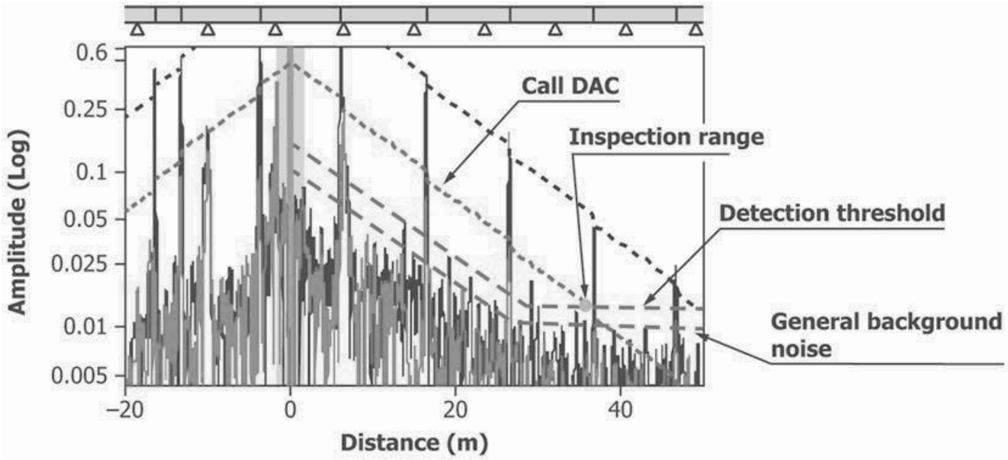

FIG. 2 Example of the GWT Result Showing How the Inspection Range is Defined

8.20.1 *Signal interpretation*—Interpretation of GWT signals is the difficult part of this method. A number of tools is available to help analyzing and distinguishing signals between various features, and these tools include:

8.20.1.1 *Shape of Reflected Signal*—The shape provides information on the axial length of a feature. An irregular reflection is typically associated with a feature that extends along the pipe such as a corrosion patch, whereas a short uniform reflection would indicate a short reflector such as a weld.

8.20.1.2 *Amplitude*—The signal amplitude is indicated by the relative signal amplitude of the axi-symmetric wave mode (that is, torsional or longitudinal mode), in terms of CSC. The shape of the signal also affect the amplitude to some extent because of the interference of reflections and scattering within the discontinuity boundaries. For a defect, the amplitude correlates to the percentage of cross-section loss of the defect at that particular position.

8.20.1.3 *Axi-Symmetry*—As the axi-symmetric wave mode reflects from a non-axially symmetric feature, such as a contact support, some of the energy is converted to the non-axi-symmetric wave modes (that is, various orders of the flexural mode). Using the ratio of the reflection magnitudes between the axi-symmetric and non-axi-symmetric modes, it is possible to determine how the feature is distributed around the circumference of the pipe.

8.20.1.4 *Behavior at Different Frequencies*—Additional information can be obtained by observing the signal response of certain features at different frequencies. The amplitude and the shape of the signal for an axially short feature, such as welds, remain unchanged as the frequency is changed. However, if the axial length is long, such as a corrosion patch, multiple signals are generated within the feature, causing interference that changes with frequencies; therefore both amplitude and shape typically change with frequencies for axially long features. Additionally, the amplitude of features causing a change in stiffness, such as contact supports, is also generally frequency dependent.

8.20.1.5 *Phase*—As the signal amplitude can be caused by either an increase or a decrease in CSC, the phase information provides a way to determine the difference between them. For example, a weld which is an increase in CSC would have a different phase to that of a defect, which is a decrease in CSC. When evaluating the change in phase with respect to other reflectors, the intent is not to determine the actual phase of each reflection signal but instead determine which of the reflectors can be grouped into similar responses. The phase information is only accurate when the SNR is good, therefore this tool is not normally used alone.

8.20.1.6 *Circumferential Orientation*—Most systems provide basic information on the circumferential orientation of a feature by evaluating the response of the transducers in each of the segments of the transducer rings; while some advanced systems also offer focusing capabilities or other special views in the processing software such as C-Scan display (see example in Appendix X2).

8.20.1.7 *Attenuation Changes*—When there is a change on the expected attenuation pattern, it indicates there is a change in the pipe condition. Be it caused by general corrosion or internal deposit, further investigation is usually required to determine the source.

8.20.2 *DAC Fitting*—The DAC curves are set typically using at least two reference reflectors, commonly welds or features with a known CSC value. For this reason, it is imperative to be able to identify the signals corresponding to the reference reflectors either by the signal characteristics or visually. Note that attenuation in GWT is heavily frequency dependent; therefore DAC curves are usually set at all collected frequencies in the data. An illustration of the DAC fitting can be found in Appendix X2.

8.20.3 *Relevant Signals*—Relevant signals are generated by physical fittings of the pipe, which include, but not limited to, features such as welds, flanges, valves, elbows, T-pieces, supports, diameter changes. These features are identified both by the signal characteristics and visually, when possible, as to their positions on the pipe. It is important to correlate the guided wave indications with the visual observations of the pipe. These indications should be noted in the software of the GWT test equipment. See Annex A1 for guidelines in determining reflector characteristics.

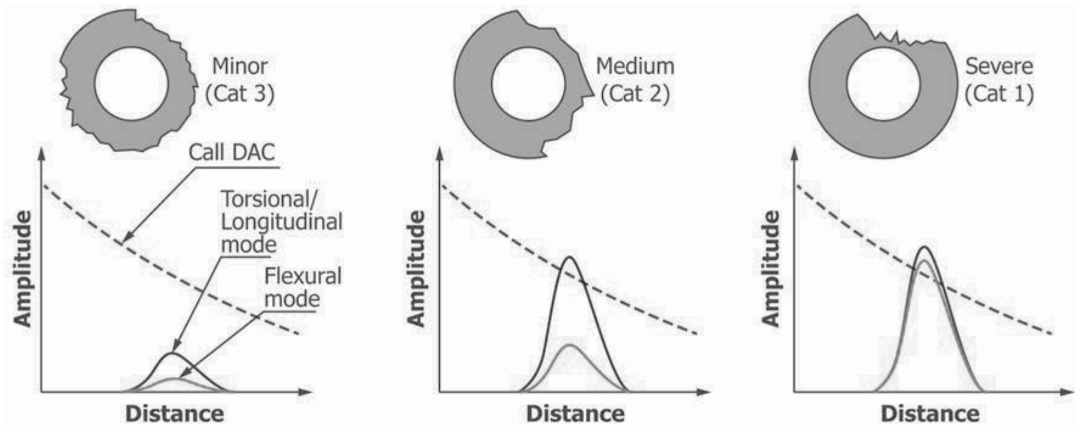

FIG. 3 Illustrations of the Signals in Each Severity Classification

8.20.4 *Non-Relevant Indications*—Non-relevant signals are those associated with noise, false echoes and other non-useable information. The following may be used to help identifying the non-relevant indications:

8.20.4.1 *Mirrors*—If the system displays a large feature in one direction and a small feature at the equal distance in the opposite direction from the test location, there is a high possibility that the smaller indication is a mirror echo. The most effective way to deal with mirror echoes is to move the transducer ring approximately 0.6 m (2 ft) and repeat the test. This causes the mirror echoes to move or disappear as the test position changes.

8.20.4.2 *Reverberations*—This usually occurs when the transducer ring is between two larger reflectors. The reverberation echo typically appears as a small indication past the first feature. If reverberation is suspected, move the transducer ring to a location outside of the two reverberating features and perform additional examinations.

8.20.4.3 *Modal Noise*—The modal noise signals typically appear close to the test location in the result, and their amplitude decays rapidly over distance. Modal noise signals are both frequency and bandwidth dependent; therefore adjusting either of the two parameters can usually eliminate them.

8.20.5 *Indications*—All other indications should be considered unclassified and further analysis should be performed on each one to determine their source and orientation.

8.20.6 *Classification of Data*—After completing the review of the other indications, those identified to be possible defects may be further classified as Minor, Intermediate and Severe. The classification is determined based on the CSC, the circumferential extent of the signal and their relationships with the call DAC level. If the call level is set too low, inspectors are likely to overcall; while if the Call level is set too high, inspectors are likely to under-call. It is important that the call level set reflects the detection requirements which should be agreed between parties beforehand. In general, each classification can be summarized as follow:

8.20.6.1 *Minor (Cat 3)*—These are considered to be indications which are shallow and/or extend around the circumference. They are not highly concentrated. Both the symmetric (that is, torsional mode) and non-symmetric (Flexural mode) modes are below the call DAC level.

8.20.6.2 *Medium (Cat 2)*—These are areas where there is more depth than the Minor indications but still are not highly concentrated. The symmetric mode is above, while the non-symmetric mode is below the call DAC level.

8.20.6.3 *Severe (Cat 1)*—These are areas that have deep indications, or are highly concentrated, or both, in an area of the pipe. They are considered very likely to produce a penetration of the pipe wall. Both the symmetric and non-symmetric modes are above the call DAC level. Signal examples of each classification based on the defect profile around the circumference that is axially short, are shown in Fig. 3.

8.20.7 *Severity Classification Use and Significance*—Assigning a severity classification should be used for reference, classification of indications and setting priorities for follow-up inspection. The categories are assigned based on the amplitudes of the axi-symmetric and non-axi-symmetric reflections, and their relations to the Call DAC level. It is, therefore, important that the call DAC level percentage or similar detection sensitivity requirement is specified in the contractual agreement which reflects the requirements of the industry. The GWT does not provide information regarding the remaining wall thickness or nature of the damage. This information can only be obtained as a result of follow-up inspection with other NDE methods on the areas where relevant indications associated with defects have been identified. GWT is a method for detection and classification of damage, and their result shall be treated as qualitative only.

9. Report

9.1 The test report shall document the results of the inspection. It must have all information to be able to reproduce the test at a future date if desired. Most, if not all, the items detailed in 8.10 should be included. Additionally all observations obtained from visual inspection, thickness measurements with UT and other pertinent information that is deemed as having an effect on the quality, or characteristics, or both, of the data or results should be recorded and included in the final report. All relevant and non-relevant indications identified during the examination should be included with a classification provided those reflections deemed to be associated with defects. All results from follow-up inspection with other NDE methods shall be included in the report if available.

10. Keywords

10.1 guided waves; Guided Wave Testing; NDT of pipes; pipeline inspection

ANNEX

(Mandatory Information)

A1. REFLECTOR CHARACTERISTICS

A1.1 See Table A1.1.

TABLE A1.1 Reflector Characteristics

FEATURE	VISUAL	AMPLITUDE	SHAPE	FREQUENCY	SYMMETRY	PHASE	ORIENTATION
Flange	Likely visible	Typically the highest	Irregular	Inconsistent	Symmetric	N/A	Fully circumferential
Weld	May be visible if not insulated	Medium	Clean, uniform, single echo	Consistent across wide range	Symmetric	Same as all welds	Fully circumferential
Elbow	Likely visible	Medium	1st Weld: Clean, uniform 2nd Weld: Mostly uniform	1st Weld: Consistent 2nd Weld: Inconsistent	1st Weld: Symmetric 2nd Weld: Non-symmetric	N/A	1st Weld: Fully circumferential 2nd Weld: Depending on elbow direction
Valve/Drain	Likely visible	Medium	Small size: Uniform Large size: Irregular	Small size: Consistent Large size: Inconsistent	Non-symmetric	N/A	Either top or bottom of the pipe
T-piece	Likely visible	Medium	Irregular	Inconsistent	Non-symmetric	N/A	Partial circumferential
Reducer	May be visible if not insulated	Medium	Irregular	Inconsistent	Symmetric	N/A	Fully circumferential
Short contact	Support likely visible	Low	Clean, uniform, single echo	Inconsistent	Non-symmetric	N/A	Bottom
Long contact	Support likely visible	Low	Irregular	Inconsistent	Non-symmetric	N/A	Bottom
Short Clamp support	Likely visible	Medium	Clean, uniform, single echo	Inconsistent	Symmetric	N/A	Fully circumferential
Axial support (welded)	Likely visible	Medium	Irregular	Inconsistent	Non-symmetric	N/A	Bottom
Saddle support	Likely visible	Medium	Irregular	Inconsistent	Non-symmetric	N/A	Bottom

APPENDIXES

(Nonmandatory Information)

X1. ATTENUATION

X1.1 Attenuation is the signal loss as it propagates along a structure. The loss can be caused by a combination of factors – dissipation, mode conversion, scattering due to surface roughness, absorption into other mediums and others. The rate of signal decay is the factor which determines the maximum test range for any given set up.

X1.2 *Attenuation Rate*—Attenuate rate is typically specified in loss per rate of distance traveled. This would be expressed as dB/m. occasionally, if different frequencies have a significantly different attenuation rate it may be expressed as either dB/kHz or dB/kHz-m.

X1.3 Typical attenuation rates and average test range in each direction for different test pipe configurations are found in Table X1.1.

TABLE X1.1 Typical Attenuation Rates and Average Test Range in Each Direction for Different Test Pipe Configurations

Test Condition	Typical Attenuation	Typical Range of Test
Clean, Straight Pipe	-0.15 to -0.5dB/m (-0.046 to -0.17dB/ft)	50–200 m (164–656 ft)
Clean, Wool Insulated	-0.17 to -0.75dB/m (-0.052 to -0.23 dB/ft)	40–175 m (131–574 ft)
Insignificant/Minor Corrosion	-0.5 to -1.5 dB/m (-0.152 to -0.457dB/ft)	20–50 m (65.6–164 ft)
Significant Corrosion	-1 to -2 dB/m (-0.305 to -0.61dB/ft)	15–30 m (49.2–98.4 ft)
Kevlar Wrapped	-0.15 to -1 dB/m (-0.046 to -0.305dB/ft)	30–200 m (98.4–656 ft)
Spun Epoxy Coating	-0.75 to -1 dB/m (-0.23 to -0.305dB/ft)	30–50 m (98.4–164 ft)
Well Packed Earth	-1 to -2 dB/m (-0.305 to -0.61dB/ft)	15–30 m (49.2–98.4 ft)
Thin (<2.5mm), Hard Bitumen Tape	-1.25 to -6 dB/m (-0.381 to -1.83dB/ft)	5–25 m (16.4–82 ft)
Thick (>2.5mm), Soft Bitumen Tape	-4 to -16 dB/m (-1.22 to -4.88dB/ft)	2–8 m (6.56–26.24 ft)
Well Bonded Concrete Wall	-16 to -32 dB/m (-4.88 to 9.76dB/ft)	1–2 m (3.28–6.56 ft)
Grout Lined Pipe	-1 to -3 dB/m (-0.305 to 0.91dB/ft)	10–30 m (32.8–98.4 ft)
Loosely Bonded Concrete Wall	-4 to -16 dB/m (-1.22 to -4.88dB/ft)	2–8 m (6.56–26.24 ft)

X2. TYPICAL LINEAR AMPLITUDE VERSUS DISTANCE GWUT DISPLAY

X2.1 See Fig. X2.1.

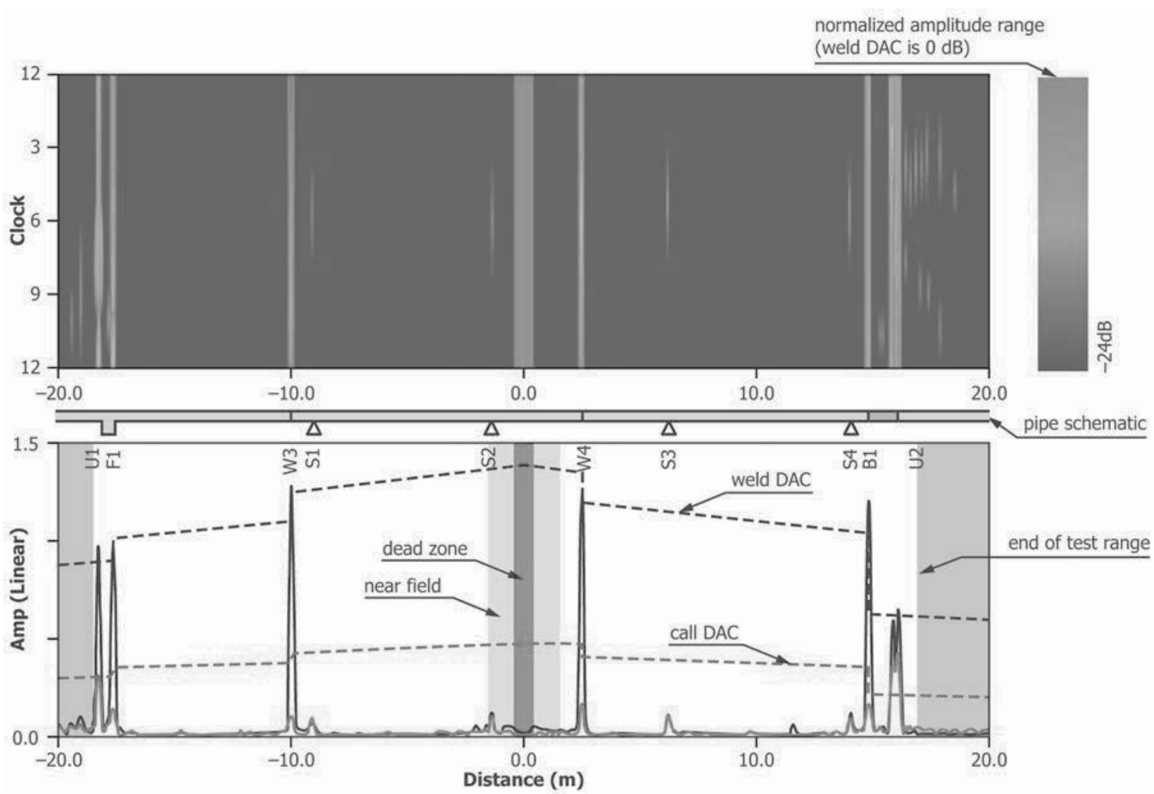

FIG. X2.1 An Example of the A-Scan Type (Bottom) and C-Scan Type (Top) Results from GWT (The C-scan plot provides the circumferential orientation, displayed as the clock position, for the corresponding A-scan signal at the bottom.)

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STANDARD PRACTICE FOR GUIDED WAVE TESTING OF ABOVE GROUND STEEL PIPING WITH MAGNETOSTRICTIVE TRANSDUCTION

SE-2929

(Identical with ASTM Specification E2929-13.)

Standard Practice for Guided Wave Testing of Above Ground Steel Piping with Magnetostrictive Transduction

1. Scope

1.1 This practice provides a guide for the use of waves generated using magnetostrictive transduction technology for guided wave testing (GWT) welded tubulars. Magnetostrictive materials transduce or convert time varying magnetic fields into mechanical energy. As a magnetostrictive material is magnetized, it strains. Conversely, if an external force produces a strain in a magnetostrictive material, the material's magnetic state will change. This bi-directional coupling between the magnetic and mechanical states of a magnetostrictive material provides a transduction capability that can be used for both actuation and sensing devices.

1.2 GWT utilizes ultrasonic guided waves in the 10 to approximately 250 kHz range, sent in the axial direction of the pipe, to non-destructively test pipes for discontinuities or other features by detecting changes in the cross-section or stiffness of the pipe, or both.

1.3 GWT is a screening tool. The method does not provide a direct measurement of wall thickness or the exact dimensions of discontinuities. However, an estimate of the severity of the discontinuity can be obtained.

1.4 This practice is intended for use with tubular carbon steel products having nominal pipe size (NPS) 2 to 48 corresponding to 60.3 to 1219.2 mm (2.375 to 48 in.) outer diameter, and wall thickness between 3.81 and 25.4 mm (0.15 and 1 in.).

1.5 This practice only applies to GWT of basic pipe configuration. This includes pipes that are straight, constructed of a single pipe size and schedules, fully accessible at the test location, jointed by girth welds, supported by simple contact supports and free of internal, or external coatings, or both; the pipe may be insulated or painted.

1.6 This practice provides a general practice for performing the examination. The interpretation of the guided wave data obtained is complex and training is required to properly perform data interpretation.

1.7 This practice does not establish an acceptance criterion. Specific acceptance criteria shall be specified in the contractual agreement by the cognizant engineer.

1.8 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E543 Specification for Agencies Performing Nondestructive Testing

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

E1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments

E2775 Practice for Guided Wave Testing of Above Ground Steel Pipework Using Piezoelectric Effect Transduction

IEEE/SI-10 American National Standard for Metric Practice

2.2 *Other Standards:*

SNT-TC-1A Personnel Qualification and Certification in Non-Destructive Testing

3. Terminology

3.1 Definitions of terms specific to this standard are provided in this section. Some common terms such as *defect* may be referenced to Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *circumferential extent*—the length of a discontinuity in the circumferential direction, usually given as a percentage of the pipe circumference.

3.2.2 *circumferential orientation*—the circumferential position of a localized indication on the pipe, usually given as the clock position or degrees from the top circumferential position of the pipe.

3.2.3 *coherent noise*—indications caused by real discontinuities causing a background noise, which exponentially decays with distance (see Terminology E1316).

3.2.4 *cross-sectional area change (CSC)*—the change in the circumferential cross-section of pipe from its nominal total cross-section, usually given in percentage.

3.2.5 *dead zone*—this is an area that can be up to 1 m (3 ft) long on either side of the transducer ring that is not inspected during the testing. The area of the dead zone is a function of the excitation frequency and the number of cycles transmitted. The area is inversely related to frequency and directly related to the number of cycles.

3.2.6 *estimated cross-sectional loss (ECL)*—this is sometimes used instead of Cross-Sectional Area Change, where the feature is related to a defect.

3.2.7 *flexural wave*—wave propagation mode that produces bending motion in the pipe.

3.2.8 *guided wave (GW)*—stress waves travelling in a structure bounded in the geometry and configuration of the structure.

3.2.9 *guided wave testing (GWT)*—non-destructive test method that utilizes guided waves.

3.2.10 *incoherent noise*—random signals caused by electrical and ambient radio frequency signal pollution, giving rise to a constant average noise floor. The terms "Ambient Noise" and "Random Noise" are also used.

3.2.11 *pipe feature*—pipe components including but not limited to weld, support, flange, bend, and flaw (defect) cause reflections of a guided wave due to a change in geometry.

3.2.12 *reflection amplitude*—the amplitude of the reflection signal typically reported as CSC or reflection coefficient.

3.2.13 *reflection coefficient*—a parameter that represents the amplitude of reflected signal from a pipe feature with respect to the incident wave amplitude, usually expressed in percentage and called "% reflection." Used in lieu of CSC to characterize the severity of indications.

3.2.14 *reflector orientation*—the circumferential position of the feature on the pipe. This is reported as the clock position or degrees with regards to the orientation of the transduction device.

3.2.15 *shear wave couplant*—couplant designed specifically to effectively couple directly generated shear waves (waves not generated through refraction of longitudinal waves).

3.2.16 *signal to noise ratio (SNR)*—ratio of the amplitude of any signal of interest to the amplitude of the average background noise which includes both coherent and non-coherent types of noise.

3.2.17 *test location*—location where the transduction device is placed on the pipe for inspection.

3.2.18 *time controlled gain (TCG)*—gain applied to the signal as a function of time or distance from the initial pulse used to compensate wave attenuation in the pipeline. The TCG normalizes the amplitude over the entire time scale displayed. For example, using TCG, a 5 % reflector near the probe has the same amplitude as a 5 % reflector at the end of the time display. The TCG plot can be used in lieu of DAC curve plot.

3.2.19 *torsional wave*—wave propagation mode that produces twisting motion in the pipe.

3.2.20 *transduction device*—a device used to produce and detect guided waves. It is commonly called "guided wave probe."

3.2.21 *wave mode*—a particular form of propagating wave motion generated into a pipe, such as flexural, torsional or longitudinal.

4. Summary of Practice

4.1 GWT evaluates the condition of metal pipes to primarily establish the severity classification of defects by applying GW over a typical test frequency range from 10 to approximately 250 kHz which travels along the pipe. Reflections are generated by the change in cross-sectional area or local stiffness of the pipe, or both.

4.2 The transduction device attached around the pipe generates guided waves that travel in the pipe wall. The direction of wave propagation is controlled or can be in both directions simultaneously. These guided waves can evaluate long lengths of pipe and are especially useful when access to the pipe is limited.

4.3 This examination locates areas of thickness reduction(s) and provides a severity classification as to the extent of that damage. The results are used to assess the condition of the pipe, to determine where damaged areas are located along the length of the pipe, and their circumferential position on the pipe (when segmented transmitters or receivers, or both, are used). The information can be used to program and prioritize additional inspection work and repairs.

4.4 Reflections produced by pipe features (such as circumferential welds, elbows, welded supports, vents, drainage, insulation lugs, and other welded attachments) and that are not associated with areas containing possible defects are considered as relevant signals and can be used for setting GW system defect detection sensitivity levels and time calibration.

4.5 Other sources of reflection may include changes in surface impedance of the pipe (such as pipe supports and clamps). These reflections are normally not relevant, but should be analyzed and classified in an interpretation process. In the advanced applications which are not covered by this practice, these changes may also include various types of external/internal coatings, entrance of the pipe to ground, or concrete wall.

4.6 Inspection of the pipe section immediately connecting to branch connections, bends or flanges are considered advance applications which are not covered by this practice.

4.7 False indications are produced by phenomena such as reverberations, incomplete control of wave propagation direction, distortion at elbows, and others. These signals should be analyzed and classified as false echoes in the interpretation process.

5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for using GWT to locate areas in metal pipes in which wall loss has occurred due to corrosion or erosion.

5.2 GWT does not provide a direct measurement of wall thickness, but is sensitive to a combination of the CSC (or reflection *coefficient*) and circumferential extent and axial extent of any metal loss. Based on this information, a classification of the severity can be assigned.

5.3 The GWT method provides a screening tool to quickly identify any discontinuity along the pipe. Where a possible defect is found, a follow-up inspection of suspected areas with ultrasonic testing or other NDT methods is normally required to obtain detailed thickness information, nature, and extent of damage.

5.4 GWT also provides some information on the axial length of a discontinuity, provided that the axial length is longer than roughly a quarter of the wavelength.

5.5 The identification and severity assessment of any possible defects is qualitative only. An interpretation process to differentiate between relevant and non-relevant signals is necessary.

5.6 This practice only covers the application specified in the scope. The GWT method has the capability and can be used for applications where the pipe is insulated, buried, in road crossings, and where access is limited.

5.7 GWT shall be performed by qualified and certified personnel, as specified in the contract or purchase order. Qualifications shall include training specific to the use of the equipment employed, interpretation of the test results, and guided wave technology.

5.8 A documented program which includes training, examination, and experience for the GWT personnel certification shall be maintained by the supplying party.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

6.2 *Personnel Qualifications*—Unless otherwise specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with one of the following:

6.2.1 Personnel performing examinations to this practice shall be qualified in accordance with SNT-TC-1A and certified by the employer or certifying agency, as applicable. Other equivalent qualification documents may be used when specified in the contract or purchase order. The applicable revision shall be the latest unless otherwise specified in the contractual agreement between parties.

6.2.2 Personnel qualification accredited by the GWT equipment manufacturers.

6.3 This practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.4 *Qualifications of Non-destructive Testing Agencies*—Unless otherwise specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543, and the applicable edition of Specification E543 shall be specified in the contractual agreement.

6.5 *Procedure and Techniques*—The procedures and techniques to be utilized shall be specified in the contractual agreement. It should include the scope of the inspection, that is, the overall NDT examination intended to identify and estimate the size of any indications detected by the examination, or simply locate and provide a relative severity classification.

6.6 *Surface Preparation*—The pre-examination site preparation criteria shall be in accordance with 8.3 unless otherwise specified.

6.7 *Required Interval of Examination*—The required interval or the system time in service of the examination shall be specified in the contractual agreement.

6.8 *Extent of the Examination*—The extent of the examination shall be in accordance with 6.5 above unless otherwise specified. The extent should include but is not limited to:

6.8.1 The sizes and length(s) of pipes to be inspected.

6.8.2 Limitations of the method in the areas of application.

6.8.3 Drawings of pipe circuits, pipe nomenclature and identification of examination locations.

6.8.4 Pipe access method(s).

6.8.5 Safety requirements.

6.9 *Reporting Criteria*—The test results of the examination shall be documented in accordance with the contractual agreement. This may include requirements for permanent records of the collected data and test reports. The report documentation should include:

6.9.1 Equipment inspector and test results reviewed by (if applicable).

6.9.2 Date and time of the examination performed.

6.9.3 Equipment used.

6.9.4 Test procedure/specification used.

6.9.5 Acceptance criteria.

6.9.6 Inspection location.

6.9.7 Identification of areas inspected.

6.9.8 Identification of the inspection range.

6.9.9 Any other information deemed necessary to reproduce or duplicate test results.

6.10 *Reexamination of Repairs/Rework Items*—Examination of repaired/reworked items is not addressed in this practice and, if required, shall be specified in the contractual agreement.

7. Apparatus

7.1 The GWT apparatus shall include the following:

7.1.1 *Transduction Device Transmitter*—A transduction system using the magnetostrictive effect for the generation of guided wave modes with axial propagation on cylindrical pipes.

7.1.2 *Transduction Device Receiver*—A system for the detection of the signal reflected by the geometric features on the pipe, which can be the same as the transmitter or an analogous transduction system.

7.1.3 *Instrumentation*—The GWT instrumentation shall be capable of generating, receiving and amplifying electrical pulses within the frequency range used by GWT. Additionally, it shall be capable of communicating with a computer so that collected data can be processed and recorded.

7.1.4 *Processing System*—This is a software interface for processing and analyzing the signal, capable of distinguishing at least one guided wave mode for the specific detection system.

8. Examination Procedure

8.1 It is important to ensure that the proposed inspection falls within the capabilities of the technology and equipment and that the using party or parties understand the capabilities and limitations as it applies to their inspection.

8.2 *Pre-examination Preparation:*

8.2.1 All test equipment shall have current and valid calibration certificates.

8.2.2 Follow the equipment manufacturer's recommendations with regard to equipment pre-test verification and check list. As a minimum this check list should include but is not limited to:

8.2.2.1 Electronics fully operational.

8.2.2.2 Verification that interconnection cables are in good condition and functioning correctly.

8.2.2.3 Correct transduction device size for the intended pipes.

8.2.2.4 The transduction device is functioning correctly.

8.2.2.5 Any computer used with the system is functioning correctly and has sufficient storage capacity for the intended work scope.

8.2.2.6 Supplementary equipment, such as an ultrasonic flaw detector or specialized pit gauges are available and functioning correctly.

8.2.2.7 All necessary accessories such as tape-measure and markers are available.

8.2.3 Ensure all site safety requirements and procedures are reviewed and understood prior to starting any field work.

8.3 *Examination Site Preparation:*

8.3.1 *Pipe Surface Condition*—To obtain the best coupling condition, the surface shall be clean and free of any loose paint, dirt, oxidation, or any foreign substance that may interfere in energy transmission. Wire brushing or sanding, or both, are usually sufficient to prepare the surface if it is safe and permitted to do so.

8.3.2 *Insulation*—If the pipe is insulated, carefully remove an amount of insulation for mounting the magnetostrictive transduction device to the pipe (a minimum of 0.3 m (1 ft). Prior to removing the insulating material ensure it is safe and permissible to do so.

8.3.3 GWT is most effective for testing long lengths of pipe. However, short radius elbows distort GWT signals, making interpretation of signals obtained at distances beyond the elbow difficult. Where possible, it is good practice to exclude from evaluation sections of pipe immediately after elbows. In any case, no signals after two elbows should be analyzed. It is sometimes better to take additional data at different locations than interpreting a signal beyond multiple features or those with complicated geometries. Consider taking a second reading at a second test location (as recommended by the manufacturer) for confirmation of features and false echo identification.

8.3.4 *Visual Inspection*—Visually inspect the pipe where possible for potential damage areas or corrosion, such as the support areas, if possible defect indications are found in the GWT result.

8.3.5 *Surface Temperature*—Verify that the surface temperature of the pipe to be tested is within the manufacturer's specifications for the equipment.

8.3.6 *Thickness Check*—Before mounting the transduction device, verify that there is no degradation in the pipe wall thickness at the test location. As a minimum requirement, thickness measurements at no less than four equally spaced positions around the pipe should be made using an appropriate thickness measuring instrument and procedure. Some agencies may also require thickness measurement of the entire dead zone. It is important to note that attaching the transduction device at locations with very severe corrosion may cause further damage to the pipe if a mechanical force system is used for coupling.

8.4 *Transduction Device*—The transduction device should be attached to the pipe using proper coupling methods.

8.5 *Couplant*—Good coupling is obtained by simply applying sufficient mechanical force on the transduction device or by the use of epoxy bonding or shear wave couplant on the transduction device in lieu of mechanical force devices.

8.6 *Choosing Test Location*—After completing the examination site preparation outlined in 8.3, attach the transduction device to the pipe. The test location should be chosen so as to minimize false echoes. Avoid placing the transduction device near a feature as the corresponding signal may appear within the dead zone. In the dead zone, no echoes are received, as a practice, a minimum of 0.13 m (0.4 ft) should be used to the first area of inspection. Features such as welds which are used for the DAC curves or TCG correction fitting, should be outside the dead zone to ensure valid amplitude. Additionally, transduction devices should not be positioned equidistant between two features to avoid masking of the mirror echoes, if any.

8.7 *Attaching the Transduction Device*—When attaching the transduction device, it is important to ensure that the FeCo flat strip is in good contact with the pipe and that the transduction device is mounted parallel to the circumference of the pipe. Further, it is important to apply the appropriate air pressure, clamp torque settings (if dry coupling is used), or bonding or shear wave couplant as specified in the manufacturer's operating manual for proper installation of the transduction device.

8.8 *Directionality and Orientation*—The reported directionality and orientation of the features depend on the way the transduction device is installed. It is good practice to keep the direction between different test locations the same, and in the direction of product flow if known. To ensure the correct orientation is reported, a segmented transduction device should be attached in accordance with the GWT manufacturer's recommendations.

8.9 *Reproducibility*—The examination pipe should be marked with a paint marker indicating the transduction device position, direction, and date of examination. This can assist, should it be necessary, to reproduce the examination in the future. This information should also be included in the examination documentation.

8.10 *Test Location Information*—The following amount of information about the test location is needed in the processing software to ensure the exact location can be identified. This information to be recorded shall include the following:

8.10.1 *Site Name*—The name of the site, which may include the plant name, plant unit number, approximate mile marker or any relevant reference if available.

8.10.2 *Pipe*—The pipe identification if available. If not, the pipe diameter should be recorded.

8.10.3 *Datum*—The reference feature from which the test location is measured. Typical reference features used are welds and flanges.

8.10.4 *Distance*—The distance between the datum and the center of the transduction device shall be recorded. It is also important to include both positive and negative signs in front of the distance value for positive and negative direction of the ring respectively.

8.11 *Coupling Check*—It is important that all transduction devices are well coupled to the pipe. Prior to collecting any test data, perform a coupling test in accordance with the manufacturer's guidelines.

8.12 *Examination Precautions*—There are several precautions that need to be addressed when analyzing the collected data. These include:

8.12.1 *Dead Zone*—The length of the dead zone is a function of the excitation frequency and the number of cycles transmitted. The area is inversely related to frequency and directly related to the number of cycles. In order to get a 100 % coverage of the pipe there are two options:

8.12.1.1 Inspection of the dead zone with an alternative NDT method such as ultrasonic testing.

8.12.1.2 Collect additional data from another test location that provides an overlap of the previous test location. Some agencies require a 20 % overlap on all data collected where possible.

8.12.2 *Expected Examination Range*—There are several physical test conditions on or around the pipe which affect the maximum examination range that can be achieved (see Appendix X1 for more detail). There are also equipment parameters such as frequency and gain settings, which can be varied so as to optimize the test parameters for specific test conditions on or around the pipe. The maximum inspection range is defined in 8.18.

8.12.3 *False Echo (False Signals)*—Signals other than from a real feature. Care should be taken to minimize the potential for false signals to interfere with the interpretation of the data. The most common sources of false echoes are:

8.12.3.1 *Reverberations*—Multiple reflections either between two large features along the pipe, or between the two ends of a long feature. Echoes caused by reverberations typically have small amplitudes.

8.12.3.2 *Mirrors*—Occurs due to insufficient control of the propagation direction of the guided wave. The mirror echo appears at the same distance from transduction device, but the opposite direction, as the real reflection.

8.12.3.3 *Modal Noise*—Occurs when the transduction device is unable to control all the wave modes propagating in the pipe. Even though the magnetostrictive transduction device generates mostly torsional waves, reflectors in the pipe can generate various guided wave modes; therefore, some modal noise exists in the received waveform.

8.13 *Collection Protocol*—The collection protocol varies certain collection parameters to optimize the data quality based on the pipe diameter and the expected mechanism(s) on and around the pipe. Most manufacturers include a procedure for determining the optimum collection parameters automatically for a specific test condition. These collection parameters include:

8.13.1 *Frequency*—GWT is typically performed at frequencies between approximately 10 and 250 kHz. When performing a test, data should be collected with enough different frequencies so as to be able to categorize each indication.

8.13.2 *Bandwidth*—Changing the signal bandwidth can assist in resolving the attributes of a signal. A narrow bandwidth enhances the frequency dependency of a signal while a wider frequency bandwidth can improve the axial resolution of signals such as closely spaced reflections.

8.13.3 *Wave Mode*—The GWT uses an axi-symmetric wave mode excitation which generates a torsional wave mode.

8.14 *Data Collection*—After installing the transduction device and performing the coupling check, the next step of the examination procedure is data collection. It is important that the data recorded are sufficient and comprehensive to evaluate and interpret any signals which may be present on the pipes. Choose the most appropriate collection protocol (see 8.13) and collection range to perform the initial data collection as per the equipment manufacturer's guidelines. Immediately after the data collection, it is important to review the collected data to ensure proper operation of the equipment during the test and the quality meets the required standard. The data review should include an evaluation of the SNR and the transducer balance. Poor SNR is usually caused by poor coupling of the magnetostrictive transduction device, poor magnetic conditioning of the magnetostrictive strip material, or high incoherent noise. Should there be any significant problems observed in the data, the data should be discarded and the problem addressed.

8.15 *Distance Amplitude Correction (DAC) or Time Corrected Gain (TCG)*—As the excitation signal travels away from the transduction device, its signal amplitude decreases. There are several reasons for the energy loss, including material damping, reflections at features, energy leakage, and surface conditions. The DAC or TCG provides the ability to determine the signal amplitude at a point away from the transduction device. This allows for determining the relative amplitude of an echo, expressed in either CSC, ECL, or reflection coefficient, at a given distance. When using the magnetostrictive transduction guided wave technology, DAC or TCG gain compensation can be used. When the DAC curve is used, a curve representing the attenuation as a function of distance for a given reflection amplitude is displayed on the waveform screen. When TCG is used, the gain of the unit is corrected so that a given amplitude reflector has the same amplitude across the entire length of the exam, removing the effect of attenuation on the displayed amplitude. If the DAC curves are set too low or the TCG is applied incorrectly, the size of possible defects may be overestimated or underestimated, and vice versa. Therefore, it is vital that the DAC levels or the TCG, or both, are set correctly before interpreting the data as they provide reference CSC or reflection coefficient levels to all other signals for comparison. There are four DAC curves or TCG settings that can be used in evaluating GWT reflections. Most systems provide inspectors the means of manually adjusting these curves. (Fig. 1 shows data with the DAC and TCG applied and Fig. 2 illustrates a signal with a DAC curve showing coherent and incoherent noise).

8.15.1 *Flange DAC or TCG Setting*—This is a DAC curve or TCG setting that represents the expected amplitude of a reflection from a large feature which reflects approximately a 100 % (that is, 0 dB) of the amplitude of the excitation signal and no energy can therefore pass through.

8.15.2 *Weld DAC or TCG Setting*—Pipe girth welds typically present 10 to 35 % CSC. The amount of energy reflected at the weld is the reason why the maximum number of pipe joints that can be inspected is limited.

8.15.3 *Call DAC or threshold after application of TCG*—This is the typical threshold level that is used to determine the severity of a defect if found.

8.16 *Ambient Noise*—Ambient noise causes an increase in the overall incoherent noise level. Special precautions should be taken when ambient noise is higher than normal. Most equipment manufacturers offer special protocols to test in high ambient noise areas.

8.17 *Detection Threshold (DT)*—The DT of an examination is equivalent to the sensitivity, and it is typically set to 6 dB above the background noise but it can also be manually set by the inspectors.

8.18 *Inspection Range*—The section of pipe between the transduction device and the end of test in one direction where the sensitivity is greater than the Call level (see 8.15.3). Depending on the coverage requirements, this inspection range is often used to determine the subsequent test locations. As the attenuation varies with frequency, the inspection range is normally specified for a particular frequency. The inspection range is also limited by the presence of a flange, or any feature that is not within the scope of the standard.

8.19 *Distance Standardization*—The acoustic properties of different grades of steel varies slightly, causing an offset in the reported distance of the features. The software typically uses the acoustic properties of carbon steel. In most cases, the distance offset is very small, and therefore, it is not necessary to perform distance standardization. However, where the pipe material is not carbon steel, it is good practice to standardize distance in the software against a physical measurement prior to analyzing the data. Some systems have the ability to calibrate the velocity of the material based on known locations of weld or flanges.

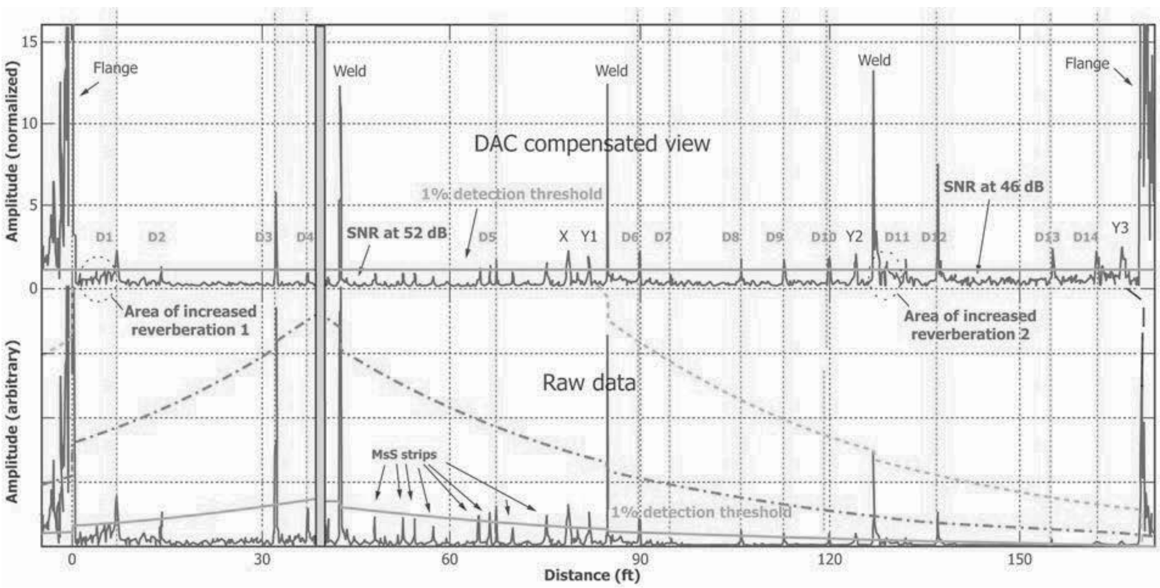

FIG. 1 Comparison of TCG data plot (Top) and its DAC curve plot (Bottom) using magnetostrictive transduction (Both results are displayed in the linear amplitude scale)

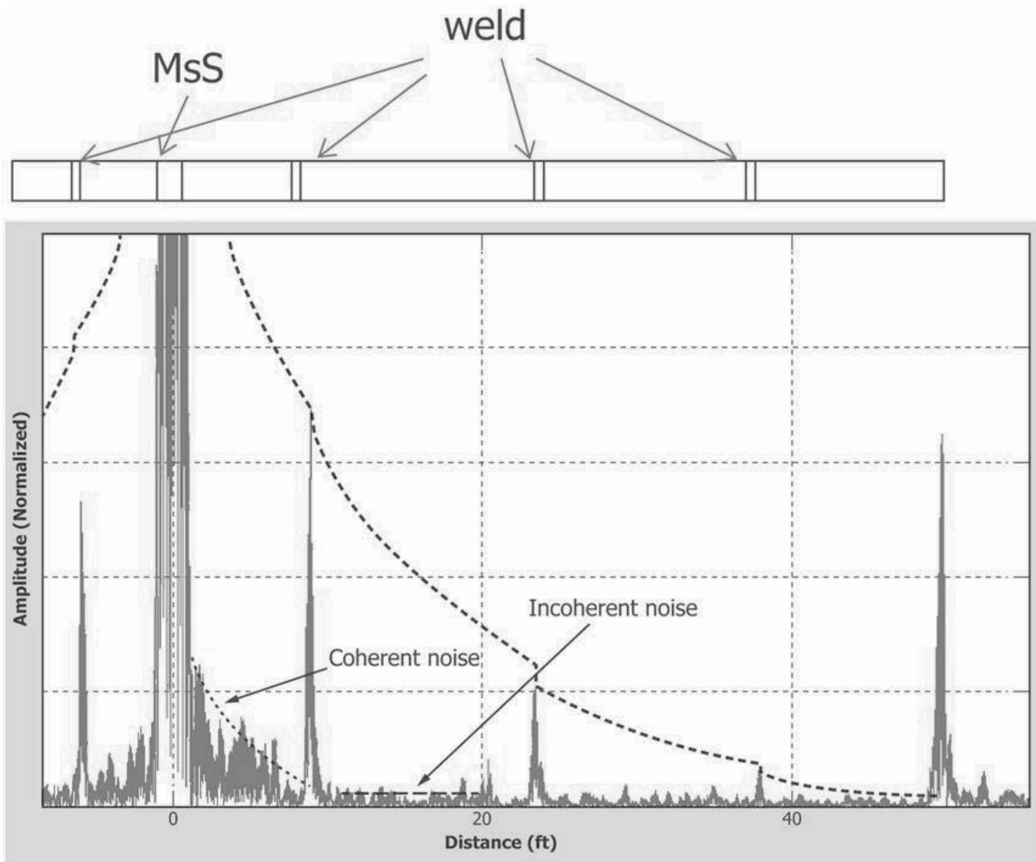

FIG. 2 MsS data plot showing a DAC curve and signals from welds and coherent and incoherent noise

8.20 *Data Review*—The initial review of the data is to separate data into relevant, non-relevant signals and indications. Data review is a process that each specific GWT system manufacturer provides detailed training in how to use their data review or data analysis software.

8.20.1 *Signal Interpretation*—Interpretation of GWT signals is the difficult part of this method. A number of tools are available to help analyzing and distinguishing signals between various features, and these tools include:

8.20.1.1 *Shape of Reflected Signal*—The shape provides information on the axial length of a feature. An irregular reflection is typically associated with a feature that extends along the pipe such as a corrosion patch, whereas a short uniform reflection would indicate a short reflector such as a weld.

8.20.1.2 *Amplitude*—The signal amplitude is indicated by the relative signal amplitude of the axi-symmetric wave, in terms of CSC or reflection coefficient. The shape of the signal also affects the amplitude to some extent because of the interference of reflections and scattering within the discontinuity boundaries. For a defect, the amplitude correlates to the percentage of cross-section loss of the defect at that particular position.

8.20.1.3 *Behavior at Different Frequencies*—Additional information can be obtained by observing the signal response of certain features at different frequencies. The amplitude and the shape of the signal for an axially short feature, such as welds, remain unchanged as the frequency is changed. However, if the axial length is long, such as a corrosion patch, multiple signals are generated within the feature, causing interference that changes with frequencies; therefore, both amplitude and shape typically change with frequencies for axially long features. Additionally, the amplitude of features causing a change in stiffness, such as contact supports, is also generally frequency dependent.

8.20.1.4 *Phase*—As the signal amplitude can be caused by either an increase or a decrease in CSC, the phase information provides a way to determine the difference between them. For example, a weld which is an increase in CSC would have a different phase to that of a defect, which is a decrease in CSC. When evaluating the change in phase with respect to other reflectors, the intent is not to determine the actual phase of each reflection signal but instead determine which of the reflectors can be grouped into similar responses. The phase information is only accurate when the SNR is good, therefore, this tool is not normally used alone.

8.20.1.5 *Attenuation Changes*—When there is a change on the expected attenuation pattern, it indicates there is a change in the pipe condition. Be it caused by general corrosion or internal deposit, further investigation is usually required to determine the source.

8.20.1.6 *DAC and TCG Fittings*—The DAC curves and TCG are set typically using at least two reference reflectors, as shown in Fig. 2, commonly welds or features with a known approximately CSC or reflection coefficient value. For this reason, it is imperative to be able to identify the signals corresponding to the reference reflectors either by the signal characteristics or visually. Note that attenuation in GWT is heavily frequency dependent; therefore, DAC curves are usually set at all collected frequencies in the data. An illustration of the DAC fitting can be found in Appendix X2.

8.20.2 *Relevant Signals*—Relevant signals are generated by physical fittings of the pipe, which include, but are not limited to, features such as welds, flanges, valves, elbows, T-pieces, supports, and diameter changes. These features are identified both by the signal characteristics and visually, when possible, as to their positions on the pipe. It is important to correlate the guided wave indications with the visual observations of the pipe. These indications should be noted in the software of the GWT test equipment. See Annex A1 for guidelines in determining reflector characteristics.

8.20.3 *Non-Relevant Indications*—Non-relevant signals are those associated with noise, false echoes and other non-useable information. The following may be used to help identify the non-relevant indications:

8.20.3.1 *Mirrors*—If the system displays a large feature in one direction and a small feature at the equal distance in the opposite direction from the test location, there is a high possibility that the smaller indication is a mirror echo. The most effective way to deal with mirror echoes is to move the transduction device approximately 0.6 m (2 ft) and repeat the test. This causes the mirror echoes to move or disappear as the test position changes.

8.20.3.2 *Reverberations*—This usually occurs when the transduction device is between two larger reflectors. The reverberation echo typically appears as a small indication past the first feature. Most of the GWT systems have software that helps analyze the presence of reverberations. If reverberation is confirmed, move the transduction device to a location outside of the two reverberating features and perform additional examinations to obtain inspection results.

8.20.4 *Indications*—All other indications should be considered unclassified and further analysis should be performed on each one to determine their source and orientation.

8.20.5 *Classification of Data*—For the magnetostrictive transduction system the classification is determined based on the reflection coefficient, and their relationships with the call DAC level. If the call level is set too low, inspectors are likely to overcall; while if the call level is set too high, inspectors are likely to under-call. It is important that the call level set reflects the detection requirements which should be agreed between parties beforehand.

8.20.6 *Severity Classification Use and Significance*—Assigning a severity classification should be used for reference, classification of indications and setting priorities for follow-up inspection. The categories are usually assigned based on criteria described in 8.20.1.1, as shown in Table 1. It is, therefore, important that the call DAC level percentage or similar detection sensitivity requirement is specified in the contractual agreement which reflects the requirements of the industry. The GWT does not provide information regarding the remaining wall thickness or nature of the damage. This information can only be obtained as a result of follow-up inspection with other NDE methods on the areas where relevant indications associated with defects have been identified. GWT is a method for detection and classification of damage, and their result shall be treated as qualitative only.

9. Report

9.1 The test report shall document the results of the inspection. It must have all information to be able to reproduce the test at a future date if desired. Most, if not all, of the items detailed in 8.10 should be included. Additionally, all observations obtained from visual inspection, thickness measurements with UT, and other pertinent information that is deemed as having an effect on the quality, or characteristics, or both, of the data or results should be recorded and included in the final report. All relevant and non-relevant indications identified during the examination should be included with a classification provided those reflections deemed to be associated with defects. All results from follow-up inspection with other NDE methods shall be included in the report if available.

10. Keywords

10.1 guided wave testing; guided waves; magnetostrictive transduction; NDT of pipes; pipeline inspection

TABLE 1 Severity Classification of Indications Observed with the Guided Waves Generated Using Magnetostrictive Transduction

Assuming the noise floor is approximately 2 % CSC		
Minor indication is 2-4 % CSC	Medium indication is 5-10 % CSC	Major indication > 10 % CSC
Assuming the noise floor is greater than 2 % CSC		
Minor indication cannot be identified	Medium indication is 5-10 % CSC	Major indication > 10 % CSC

ANNEX

(Mandatory Information)

A1. REFLECTOR CHARACTERISTICS

A1.1 See Table A1.1.

TABLE A1.1 Reflector Characteristics

Feature	Visual	Amplitude	Shape	Frequency	Symmetry	Phase	Orientation
Flange	Likely visible	Typically the highest	Irregular	Inconsistent	Symmetric	N/A	Fully circumferential
Weld	May be visible if not insulated	Medium	Clean, uniform, single echo	Consistent across wide range	Symmetric	Same as all welds	Fully circumferential
Elbow	Likely visible	Medium	1st Weld: Clean, uniform 2nd Weld: Mostly uniform	1st Weld: Consistent 2nd Weld: Inconsistent	1st Weld: Symmetric 2nd Weld: Non-symmetric	N/A	1st Weld: Fully circumferential 2nd Weld: Depending on elbow direction
Valve/Drain	Likely visible	Medium	Small size: Uniform Large size: Irregular	Small size: Consistent Large size: Inconsistent	Non-symmetric	N/A	Either top or bottom of the pipe
T-piece	Likely visible	Medium	Irregular	Inconsistent	Non-symmetric	N/A	Partial circumferential
Reducer	May be visible if not insulated	Medium	Irregular	Inconsistent	Symmetric	N/A	Fully circumferential
Short contact	Support likely visible	Low	Clean, uniform, single echo	Inconsistent	Non-symmetric	N/A	Bottom
Long contact	Support likely visible	Low	Irregular	Inconsistent	Non-symmetric	N/A	Bottom
Short Clamp support	Likely visible	Medium	Clean, uniform, single echo	Inconsistent	Symmetric	N/A	Fully circumferential
Axial support (welded)	Likely visible	Medium	Irregular	Inconsistent	Non-symmetric	N/A	Bottom
Saddle support	Likely visible	Medium	Irregular	Inconsistent	Non-symmetric	N/A	Bottom

APPENDIXES

(Nonmandatory Information)

X1. ATTENTUATION

X1.1 Attenuation is the signal loss as it propagates along a structure. The loss can be caused by a combination of factors—dissipation, mode conversion, scattering due to surface roughness, absorption into other mediums and others. The rate of signal decay is the factor which determines the maximum test range for any given set up.

X1.2 *Attenuation Rate*—Attenuation rate is typically specified in loss per rate of distance traveled. This would be expressed as dB/m. Occasionally, if different frequencies have significantly different attenuation rates, it may be expressed as either dB/kHz or dB/kHz-m.

X1.3 Typical attenuation rates and average test range in each direction for different test pipe configurations are found in Table X1.1

TABLE X1.1 Typical Attenuation Rates and Average Test Range in Each Direction for Different Test Pipe Configurations

Test Condition	Typical Attenuation, dB/m (dB/ft)	Typical Range of Test, m (ft)
Clean, Straight Pipe	-0.15 to -0.5 (-0.046 to -0.17)	50 to 200 (164 to 656)
Clean, Wool Insulated	-0.17 to -0.75 (-0.052 to -0.23)	40 to 175 (131 to 574 ft)
Insignificant/Minor Corrosion	-0.5 to -1.5 (-0.152 to -0.457)	20 to 50 (65.6 to 164)
Significant Corrosion	-1 to -2 (-0.305 to -0.61)	15 to 30 (49.2 to 98.4)
Kevlar Wrapped	-0.15 to -1 (-0.046 to -0.305)	30 to 200 (98.4 to 656)
Spun Epoxy Coating	-0.75 to -1 (-0.23 to -0.305)	30 to 50 (98.4 to 164)
Well Packed Earth	-1 to -2 (-0.305 to -0.61)	15 to 30 (49.2 to 98.4)
Thin (<2.5mm), Hard Bitumen Tape	-1.25 to -6 (-0.381 to -1.83)	5 to 25 (16.4 to 82)
Thick (>2.5mm), Soft Bitumen Tape	-4 to -16 (-1.22 to -4.88)	2 to 8 (6.56 to 26.24)
Well Bonded Concrete Wall	-16 to -32 (-4.88 to 9.76)	1 to 2 (3.28 to 6.56)
Grout Lined Pipe	-1 to -3 (-0.305 to 0.91)	10 to 30 (32.8 to 98.4)
Loosely Bonded Concrete Wall	-4 to -16 (-1.22 to -4.88)	2 to 8 (6.56 to 26.24)

X2. TYPICAL DISPLAY OF THE LINEAR AMPLITUDE VERSUS DISTANCE GWT DISPLAY USING MAGNETOSTRICTIVE TRANSDUCTION WITH SEGMENTED RECEIVERS

X2.1 See Fig. X2.1

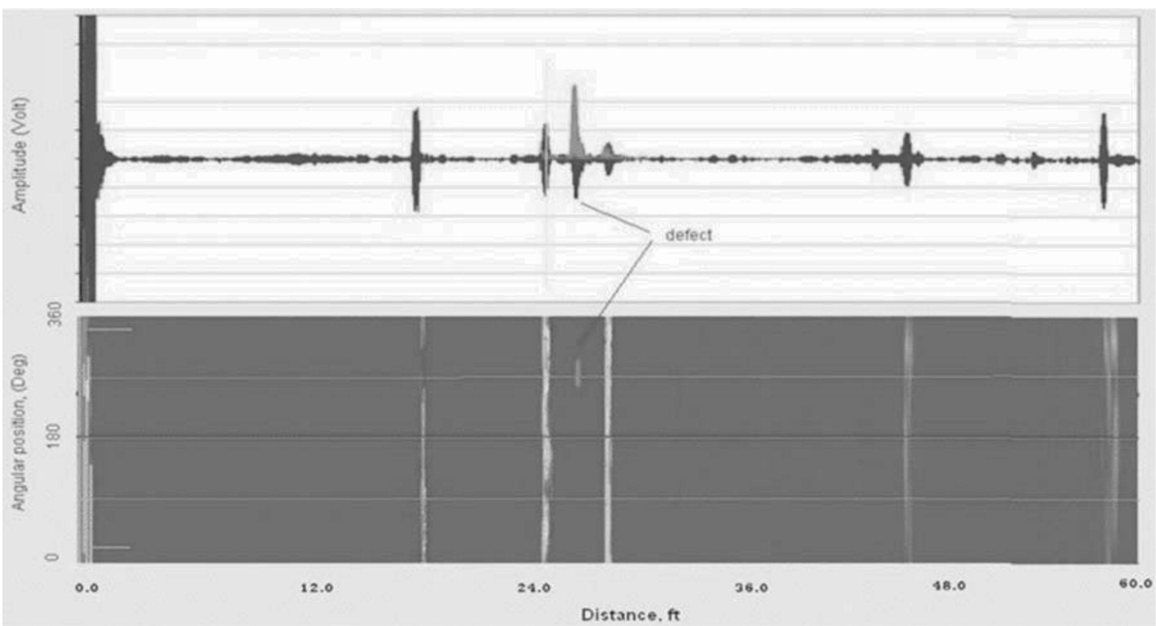

FIG. X2.1 Typical Display of the Linear Amplitude Versus Distance and B-scan Image for the Magnetostrictive Transduction GWT when Using Segmented Receivers

MANDATORY APPENDIX II
STANDARD UNITS FOR USE IN EQUATIONS

Table II-1
Standard Units for Use in Equations

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches ($in.^2$)	square millimeters (mm^2)
Volume	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Section modulus	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Moment of inertia of section	$inches^4$ ($in.^4$)	$millimeters^4$ (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (°R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi $\sqrt{\text{in.}}$)	MPa square root meters ($\text{MPa}\sqrt{\text{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

NONMANDATORY APPENDIX A
GUIDANCE FOR THE USE OF U.S. CUSTOMARY AND SI UNITS IN THE ASME BOILER AND PRESSURE VESSEL CODE

(19) A-1 USE OF UNITS IN EQUATIONS

The equations in this Section are suitable for use with either the U.S. Customary or the SI units provided in Mandatory Appendix II, or with the units provided in the nomenclatures associated with the equations. It is the responsibility of the individual and organization performing the calculations to ensure that appropriate units are used. Either U.S. Customary or SI units may be used as a consistent set. When necessary to convert from one system of units to another, the units shall be converted to at least three significant figures for use in calculations and other aspects of construction.

A-2 GUIDELINES USED TO DEVELOP SI EQUIVALENTS

The following guidelines were used to develop SI equivalents:

(a) SI units are placed in parentheses after the U.S. Customary units in the text.

(b) In general, separate SI tables are provided if interpolation is expected. The table designation (e.g., table number) is the same for both the U.S. Customary and SI tables, with the addition of suffix "M" to the designator for the SI table, if a separate table is provided. In the text, references to a table use only the primary table number (i.e., without the "M"). For some small tables, where interpolation is not required, SI units are placed in parentheses after the U.S. Customary unit.

(c) Separate SI versions of graphical information (charts) are provided, except that if both axes are dimensionless, a single figure (chart) is used.

(d) In most cases, conversions of units in the text were done using hard SI conversion practices, with some soft conversions on a case-by-case basis, as appropriate. This was implemented by rounding the SI values to the number of significant figures of implied precision in the existing U.S. Customary units. For example, 3,000 psi has an implied precision of one significant figure. Therefore, the conversion to SI units would typically be to 20000 kPa. This is a difference of about 3% from the "exact" or soft conversion of 20684.27 kPa. However, the precision of the conversion was determined by the Committee on a case-by-case basis. More significant digits were included in the SI equivalent if there was any question. The values of allowable stress in Section II, Part D generally include three significant figures.

(e) Minimum thickness and radius values that are expressed in fractions of an inch were generally converted according to the following table:

Fraction, in.	Proposed SI Conversion, mm	Difference, %
1/32	0.8	−0.8
3/64	1.2	−0.8
1/16	1.5	5.5
3/32	2.5	−5.0
1/8	3	5.5
5/32	4	−0.8
3/16	5	−5.0
7/32	5.5	1.0
1/4	6	5.5
5/16	8	−0.8
3/8	10	−5.0
7/16	11	1.0
1/2	13	−2.4
9/16	14	2.0
5/8	16	−0.8
11/16	17	2.6
3/4	19	0.3
7/8	22	1.0
1	25	1.6

(f) For nominal sizes that are in even increments of inches, even multiples of 25 mm were generally used. Intermediate values were interpolated rather than converting and rounding to the nearest millimeter. See examples in the following table. [Note that this table does not apply to nominal pipe sizes (NPS), which are covered below.]

Size, in.	Size, mm
1	25
1 1/8	29
1 1/4	32
1 1/2	38
2	50
2 1/4	57
2 1/2	64
3	75
3 1/2	89
4	100
4 1/2	114
5	125
6	150

Table continued

Size, in.	Size, mm
8	200
12	300
18	450
20	500
24	600
36	900
40	1 000
54	1 350
60	1 500
72	1 800

Size or Length, ft	Size or Length, m
3	1
5	1.5
200	60

(g) For nominal pipe sizes, the following relationships were used:

U.S. Customary Practice	SI Practice	U.S. Customary Practice	SI Practice
NPS $^1/_8$	DN 6	NPS 20	DN 500
NPS $^1/_4$	DN 8	NPS 22	DN 550
NPS $^3/_8$	DN 10	NPS 24	DN 600
NPS $^1/_2$	DN 15	NPS 26	DN 650
NPS $^3/_4$	DN 20	NPS 28	DN 700
NPS 1	DN 25	NPS 30	DN 750
NPS 1$^1/_4$	DN 32	NPS 32	DN 800
NPS 1$^1/_2$	DN 40	NPS 34	DN 850
NPS 2	DN 50	NPS 36	DN 900
NPS 2$^1/_2$	DN 65	NPS 38	DN 950
NPS 3	DN 80	NPS 40	DN 1000
NPS 3$^1/_2$	DN 90	NPS 42	DN 1050
NPS 4	DN 100	NPS 44	DN 1100
NPS 5	DN 125	NPS 46	DN 1150
NPS 6	DN 150	NPS 48	DN 1200
NPS 8	DN 200	NPS 50	DN 1250
NPS 10	DN 250	NPS 52	DN 1300
NPS 12	DN 300	NPS 54	DN 1350
NPS 14	DN 350	NPS 56	DN 1400
NPS 16	DN 400	NPS 58	DN 1450
NPS 18	DN 450	NPS 60	DN 1500

(h) Areas in square inches (in.^{2}) were converted to square millimeters (mm^2) and areas in square feet (ft^2) were converted to square meters (m^2). See examples in the following table:

Area (U.S. Customary)	Area (SI)
1 in.^{2}	650 mm^2
6 in.^{2}	4 000 mm^2
10 in.^{2}	6 500 mm^2
5 ft^2	0.5 m^2

(i) Volumes in cubic inches (in.^{3}) were converted to cubic millimeters (mm^3) and volumes in cubic feet (ft^3) were converted to cubic meters (m^3). See examples in the following table:

Volume (U.S. Customary)	Volume (SI)
1 in.^{3}	16 000 mm^3
6 in.^{3}	100 000 mm^3
10 in.^{3}	160 000 mm^3
5 ft^3	0.14 m^3

(j) Although the pressure should always be in MPa for calculations, there are cases where other units are used in the text. For example, kPa is used for small pressures. Also, rounding was to one significant figure (two at the most) in most cases. See examples in the following table. (Note that 14.7 psi converts to 101 kPa, while 15 psi converts to 100 kPa. While this may seem at first glance to be an anomaly, it is consistent with the rounding philosophy.)

Pressure (U.S. Customary)	Pressure (SI)
0.5 psi	3 kPa
2 psi	15 kPa
3 psi	20 kPa
10 psi	70 kPa
14.7 psi	101 kPa
15 psi	100 kPa
30 psi	200 kPa
50 psi	350 kPa
100 psi	700 kPa
150 psi	1 MPa
200 psi	1.5 MPa
250 psi	1.7 MPa
300 psi	2 MPa
350 psi	2.5 MPa
400 psi	3 MPa
500 psi	3.5 MPa
600 psi	4 MPa
1,200 psi	8 MPa
1,500 psi	10 MPa

(k) Material properties that are expressed in psi or ksi (e.g., allowable stress, yield and tensile strength, elastic modulus) were generally converted to MPa to three significant figures. See example in the following table:

Strength (U.S. Customary)	Strength (SI)
95,000 psi	655 MPa

(l) In most cases, temperatures (e.g., for PWHT) were rounded to the nearest 5°C. Depending on the implied precision of the temperature, some were rounded to the nearest 1°C or 10°C or even 25°C. Temperatures colder than 0°F (negative values) were generally rounded to

the nearest 1°C. The examples in the table below were created by rounding to the nearest 5°C, with one exception:

Temperature, °F	Temperature, °C
70	20
100	38
120	50
150	65
200	95
250	120
300	150
350	175
400	205
450	230
500	260
550	290
600	315
650	345
700	370
750	400
800	425
850	455
900	480
925	495
950	510
1,000	540
1,050	565
1,100	595
1,150	620
1,200	650
1,250	675
1,800	980
1,900	1 040
2,000	1 095
2,050	1 120

A-3 SOFT CONVERSION FACTORS

The following table of "soft" conversion factors is provided for convenience. Multiply the U.S. Customary value by the factor given to obtain the SI value. Similarly, divide the SI value by the factor given to obtain the U.S. Customary value. In most cases it is appropriate to round the answer to three significant figures.

U.S. Customary	SI	Factor	Notes
in.	mm	25.4	...
ft	m	0.3048	...
$in.^2$	mm^2	645.16	...
ft^2	m^2	0.09290304	...
$in.^3$	mm^3	16,387.064	...
ft^3	m^3	0.02831685	...
U.S. gal.	m^3	0.003785412	...
U.S. gal.	liters	3.785412	...
psi	MPa (N/mm^2)	0.0068948	Used exclusively in equations
psi	kPa	6.894757	Used only in text and for nameplate
psi	bar	0.06894757	...
ft-lb	J	1.355818	...
°F	°C	$^5/_9$ × (°F − 32)	Not for temperature difference
°F	°C	$^5/_9$	For temperature differences only
°R	K	$^5/_9$	Absolute temperature
lbm	kg	0.4535924	...
lbf	N	4.448222	...
in.-lb	N·mm	112.98484	Use exclusively in equations
ft-lb	N·m	1.3558181	Use only in text
ksi$\sqrt{in.}$	MPa$\sqrt{m}$	1.0988434	...
Btu/hr	W	0.2930711	Use for boiler rating and heat transfer
lb/ft^3	kg/m^3	16.018463	...

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ENDNOTES

1 For example, reference to T-270 includes all the rules contained in T-271 through T-277.3.

2 For example, T-233 requires that Image Quality Indicators be manufactured and identified in accordance with the requirements or alternatives allowed in SE-747 or SE-1025, and Appendices, as appropriate for the style of IQI to be used. These are the only parts of either SE-747 or SE-1025 that are mandatory in Article 2.

3 SNT-TC-1A, "Personnel Qualification and Certification in Nondestructive Testing;" and ANSI/ASNT CP-189, "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" and ANSI/ASNT CP-105, "ASNT Standard for Qualification of Nondestructive Testing Personnel;" published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

4 In this Code Section, the term "organization" is used generically throughout to refer to a Manufacturer, Fabricator, Installer, Assembler, or other entity responsible for complying with the requirements of this Section in the performance of nondestructive examinations.

5 Sketches showing suggested source, film, and IQI placements for pipe or tube welds are illustrated in Article 2, Nonmandatory Appendix A.

6 Refer to Article 2, Nonmandatory Appendix D for additional guidance.

7 Sample layout and technique details are illustrated in SE-1030, Appendix (Nonmandatory Information) X1, Fig. X1.1, Radiographic Standard Shooting Sketch (RSS).

8 See paragraph T-473 for cladding techniques.

9 See paragraph T-465, Calibration for Cladding.

10 When the Referencing Code Section requires the detection and evaluation of all indications exceeding 20% DAC, the gain should be increased an additional amount so that no calibration reflector indication is less than 40% FSH. As an alternate, the scanning sensitivity level may be set at 14 dB higher than the reference level gain setting. (This additional gain makes the reference DAC curve a 20% DAC curve so that indications exceeding 20% DAC may be easily identified and evaluated.).

11 A flaw need not be surface breaking to be categorized as a surface flaw.

12 The methodology contained in Article 4, Mandatory Appendix IX is intended for new construction controlled by the referencing Code Sections. When the User specifies Article 4, Mandatory Appendix IX for other uses such as post-construction examinations, they should consider specifying more than the minimum required three flaws in the qualification weld, requiring specific service-induced flaws, or possibly specifying an Article 14 high rigor type qualification.

13 Reflections from concentric cylindrical surfaces such as provided by some IIW blocks and the AWS distance calibration block may be used to adjust delay zero and sweep range for metal path calibration.

14 *Range* has been replaced on many new instruments with *velocity*.

15 The balance of the calibrations in Article 4, Nonmandatory Appendix B is written based upon the use of the indexing strip. However, the procedures may be transformed for other methods of measurements at the discretion of the examiner.

16 When manually positioning the search unit, a straightedge may be used to guide the search unit while moving to the right and left to assure that axial positioning and beam alignment are maintained.

17 Calibration by beam path measurement may be used by range control positioning by the block back reflection to the sweep division number (or multiple) equal to the measured thickness. The $\frac{1}{4}T$ SDH indication must be delay control positioned to $\frac{1}{4}$ of the sweep division number.

18 Instead of drawing a 20% DAC or 20% reference level on the instrument's screen, the gain may be increased 14 dB to make the reference level DAC curve the 20% DAC curve or 20% of the reference level.

19 The examples shown in Nonmandatory Appendix P are not necessarily typical of all defects due to differences in shape, size, defect orientation, roughness, etc.

20 "Bolting" as used in Article 5 is an all-inclusive term for any type of threaded fastener that may be used in a pressure boundary bolted flange joint assembly such as a bolt, stud, studbolt, cap screw, etc.

21 The qualification test of Mandatory Appendix IV may be performed by the User, the alternative wavelength light source manufacturer, or the magnetic particle manufacturer.

22 System background noise. For definition of symbols, see Nonmandatory Appendix A.

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