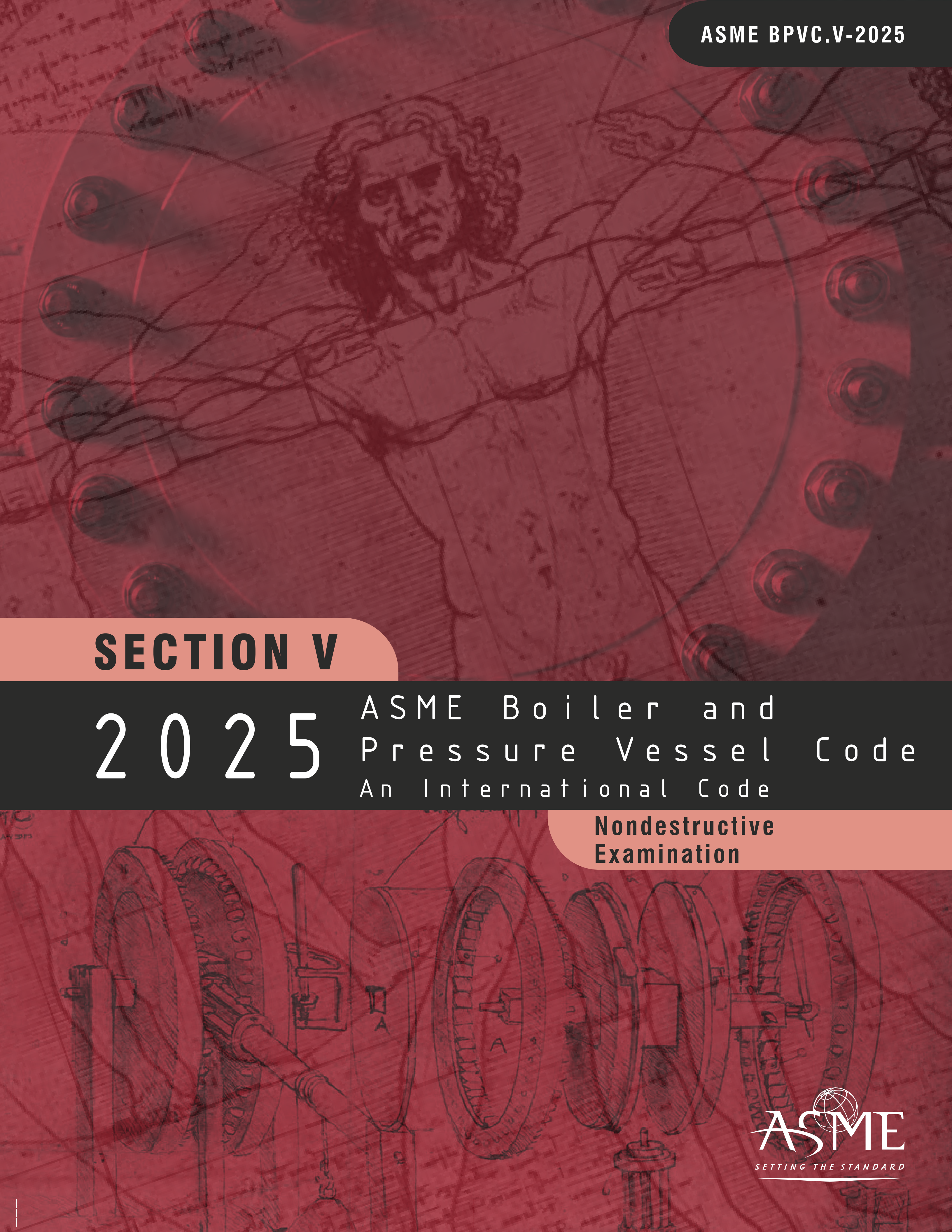

ASME BPVC.V-2025

SECTION V

2025 ASME Boiler and Pressure Vessel Code

An International Code

Nondestructive Examination

ASME
SETTING THE STANDARD

AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

V
NONDESTRUCTIVE EXAMINATION

ASME Boiler and Pressure Vessel Committee on Nondestructive Examination

The American Society of Mechanical Engineers

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FOREWORD*

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 In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees: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) Committee on Overpressure Protection (XIII)
(l) 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 to pressure integrity. The rules govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. 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. The 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 and, for nuclear items other than pressure-retaining components, structural 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 components addressed by the Code. 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.

The 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

* 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 overpressure protection.

neither requires nor prohibits the use of computers for the design or analysis of components constructed to the 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 the Code. Requests for revisions, new rules, Code cases, or interpretations shall be addressed to the staff secretary in writing and shall give full particulars in order to receive consideration and action (see the Correspondence With the Committee page). 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 the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

- *Shall* is used to denote a requirement.
- *Should* is used to denote a recommendation.
- *May* is used to denote permission, neither a requirement nor a recommendation.

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

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

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.

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CORRESPONDENCE WITH THE COMMITTEE

General

ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases 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.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number to which the proposed case applies

(4) the editions of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "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 until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

SUMMARY OF CHANGES

In this 2025 edition, the “ASTM Personnel” page has been deleted from the front matter. In addition, specifications originating with ASTM that are new or revised in this 2025 edition are formatted differently than those retained from the 2023 and earlier editions. The document following the cover sheet of each new or revised specification is the unedited ASTM specification. The ASME title for the specification and any ASME-approved exceptions to the ASTM specification are shown only on the cover sheet. Specifications affected by the new format are listed in the Summary of Changes.

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area.

Page	*Location*	*Change*
xxix	List of Sections	Title of Section XI, Division 1 revised
xxx	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xxxiii	Personnel	Updated
1	Subsection A	Articles 13, 15, 18, 19, and 21 revised, redesignated, and relocated to Subsection C
1	T-110	Subparagraph (d) revised
1	T-120	Subparagraphs (e)(1) and (e)(2) revised
14	I-121.3	“Black light” revised to “UV-A” throughout
15	I-121.4	*(1)* “Black light” revised to “UV-A” throughout *(2)* “Central” revised to “internal” throughout
25	I-121.13	Definition of *jacketing* revised
35	T-274.2	In in-text table, first column editorially reformatted
35	T-275	Revised
36	T-277.1	In subpara. (d), first cross-reference corrected to “T-282” by errata
40	T-284	Revised
44	II-221	Revised
45	II-286	First paragraph revised
57	VIII-210	Last sentence revised
58	VIII-277.2	Subparagraph (d) deleted
58	VIII-284	Revised
62	IX-221.1	Subparagraph (m) added
65	IX-284	Revised
66	IX-A-221	*(1)* First paragraph designated as IX-A-221.1 *(2)* IX-A-221.2 and Figure IX-A-221.2-1 added
68	A-210	Former Figures A-210-1 and A-210-2 editorially redesignated as tables
79	Article 3	Former Article 4, Mandatory Appendix XI revised and redesignated
90	Mandatory Appendix I (Article 3)	Added

Page	*Location*	*Change*
92	Nonmandatory Appendix A (Article 3)	Former Article 4, Nonmandatory Appendix F revised and redesignated
99	T-432	T-432.1 and T-432.2 revised
101	T-434.1.4	Revised
101	T-434.1.7.1	Revised
110	T-450	In last paragraph and T-451, cross-references revised
112	T-464.1.3	Penultimate sentence revised
122	III-471.6	Revised
127	Table V-421	First row revised
130	VII-467	Former VII-466 redesignated and title revised
131	VIII-421.1	Revised
132	VIII-467	Title revised
135	IX-483	Revised
162	Figure J-431	Note (6) revised
161	J-432	Subparagraph (b) revised
161	J-433	In subpara. (e), cross-references revised
222	T-577	Revised
226	IV-531.2	First column of in-text table editorially reformatted
229	T-660	First sentence revised
231	T-676.4	First paragraph and subparas. (c), (d), and (f) revised
231	T-677	Revised
232	II-642	Revised
232	II-643	Subparagraph (a) revised
236	Table T-721	Fourth row revised
237	T-753.2	Subparagraph (f) added
238	T-754.2	“Central” revised to “internal” throughout
239	Figure T-754.2.1	“Central” revised to “internal” throughout
239	Figure T-754.2.2	“Central” revised to “internal” throughout
239	T-761.2	Revised
242	T-765	Revised in its entirety
242	T-766	First paragraph and subpara. (b) revised
244	T-777.2	First paragraph and subparas. (c), (d), and (f) revised
245	T-779	Revised
248	I-762	Revised
248	I-762.2	Revised
249	Table III-721	Eighth row revised
249	III-761	Revised

Page	*Location*	*Change*
250	III-791	Subparagraph (d) revised
251	IV-771	Revised
251	IV-772	Term “black light” replaced throughout
252	IV-773	Revised
252	IV-791	Subparagraph (j) revised
264	II-892.3	Subparagraph (a) revised
273	VI-832	Revised
284	VIII-893.3	Subparagraph (a) revised
301	T-922	Revised
302	T-940	Added
304	T-1022	Revised
304	T-1031	*(1)* Subparagraph (a) revised *(2)* Subparagraph (b) added and subsequent subparagraphs redesignated *(3)* Subparagraphs (c) and (d) editorially revised
307	I-1021.1	First paragraph revised
307	I-1032	Subparagraph (a) revised
309	II-1021.1	First paragraph revised
309	II-1031	*(1)* Subparagraph (a) revised *(2)* Subparagraph (b) deleted and subsequent subparagraph redesignated and revised
311	III-1021.1	First paragraph revised
314	IV-1021.1	First paragraph revised
317	V-1021.1	First paragraph revised
320	VI-1021.1	First paragraph revised
320	VI-1031	Subparagraphs (a) and (b) revised
322	VIII-1021.1	First paragraph revised
325	IX-1021.1	*(1)* First paragraph revised *(2)* Subparagraph (e) added
325	Table IX-1021	Fourth row revised
328	IX-1071.8	Added
328	IX-1072.2	Subparagraph (e) added
328	IX-1080	*(1)* First paragraph designated as IX-1081 *(2)* IX-1082 added and subsequent paragraphs redesignated
330	X-1021.1	First paragraph revised
332	XI-1021.1	First paragraph and subpara. (c) revised
337	T-1122	Subparagraph (c) revised
339	T-1171	Third paragraph revised
360	T-1265	Revised

Page	*Location*	*Change*
387	T-1441.1	First paragraph revised
390	T-1472	In first paragraph and T-1472.1, "appendix" editorially revised to "Article"
391	Table T-1472.1	99% Probability of Detection data editorially reformatted
393	Mandatory Appendix I (Article 14)	*(1)* Former Mandatory Appendix II redesignated *(2)* I-1434.3 revised
400	T-1722	Revised
405	T-2025	Title revised
409	Subsection B	Boxed explanatory note on the title page of each specification revised
411	SE-94/SE-94M	Revised in its entirety
427	SE-747	Revised in its entirety
495	SE-1255	Revised in its entirety
509	SE-1416	Revised in its entirety
517	SE-1475	Revised in its entirety
525	SE-1647	Revised in its entirety
531	SE-2007	Added
557	SA-388/SA-388M	Revised in its entirety
575	SA-578/SA-578M	Revised in its entirety
603	SD-7091	Revised in its entirety
629	SE-317	Deleted
641	SE-2491	Revised in its entirety
677	SD-516	Revised in its entirety
685	SD-808	Deleted
707	SE-2297	Revised in its entirety
725	SE-709	Revised in its entirety
775	SE-243	Revised in its entirety
873	SE-2096/SE-2096M	Revised in its entirety
885	SE-2775	Deleted
887	SE-2929	Deleted
888	Subsection C	Added

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

SUBSECTION A NONDESTRUCTIVE METHODS OF EXAMINATION (25)

ARTICLE 1 GENERAL REQUIREMENTS

(25) T-110 SCOPE

(a) This Section of the Code contains requirements, methods, and techniques for nondestructive examination (NDE), which are Code requirements to the extent that 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. Nonmandatory Appendix A of this Article provides 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 Section. 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.

(25) T-120 GENERAL

(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. In every case, reference to a paragraph includes all the subparagraphs and subdivisions under that paragraph.

NOTE: For example, a reference to T-270 includes all of the rules contained in T-271 through T-277.3.

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

NOTE: 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. In many cases, Subsection B documents are not mandatory and are intended only for guidance or reference use.

(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. This written practice shall address the methods and techniques that are applicable to the organization's operations and shall be in accordance with one of the following documents:

(1) SNT-TC-1A (2024 Edition),[1] Personnel Qualification and Certification in Nondestructive Testing, with the following exceptions:

(-a) SNT-TC-1A (2024 Edition) shall not be considered a recommended practice but rather shall provide mandatory requirements. The verb "shall" is to be used in place of "should" when establishing minimum requirements of the written practice.

(-b) The provisions of paras. 8.4.4, 8.5.6, 8.6.3.2, and 8.6.4.3 are not applicable to specific and practical examinations [see (f) for rules relating to central certification programs].

(-c) The technical performance evaluation described in para. 10.2 shall be mandatory prior to recertification.

(-d) In addition to the examination requirements of para. 8.6, NDT Level III personnel shall be required to prepare a written procedure for each applicable method, meeting the requirements of an ASME construction or related inservice inspection code or standard before initial certification by each employer. For currently certified individuals, the procedure requirement shall be fulfilled at the next recertification event. Evaluation of the procedure shall be performed using a written checklist that addresses items relating to the technical and practical adequacy of the NDE procedure. Evaluation of the procedure shall be performed by the NDT Level III responsible for the applicable method and so recorded.

(-1) If the NDT Level III candidate will be required to administer practical examinations for certification to an ASME code or standard, the candidate shall complete the practical examinations required for a Level II in each applicable technique within the method with their current employer.

(-2) The NDT Level III personnel are not required to complete the requirements of (-d) for written procedure and practical examinations more than once for the current employer.

(2) ANSI/ASNT CP-189 (2024 Edition),[1] ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, except that the provisions of "paras. 6.3.2.1 and 6.3.3.3 are not applicable to specific and practical examinations [see (f) for rules relating to central certification programs].

(f) National or international central certification programs, such as ISO 9712–based programs, may alternatively be used to fulfill the written practice requirements of (e) for training, experience, general examination, basic examination, and method examination, as applicable.

(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-1-2020, 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[2] Quality Program shall stipulate how this is to be accomplished. Qualifications in accordance with a prior edition of this Section are valid until recertification. Recertification or new certification shall be in accordance with the current edition of this Section. 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

(a) When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be performed following a written procedure.

(1) The examination procedure shall comply with the applicable requirements of this Section for the particular examination method. A copy of each procedure shall be readily available to the NDE personnel for their reference and, upon request, to the Inspector.

(2) The Inspector shall be satisfied with the capability of a procedure to detect relevant discontinuities by its application in a demonstration examination on a sample with at least one known discontinuity, except where otherwise specified by the referencing Code Section. 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.

(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 on a sample with at least one known discontinuity, or by other means acceptable to the referencing Code Section and to the Inspector. This will 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 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(b)], the Code User shall specify what calibration is necessary, when calibration is required.

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.

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.

automated examination technique: a two-dimensional radiographic examination in which the radiation source and the detector are held in a predetermined fixed position, then moved in a controlled progression to perform the examination. Alternatively, the source and the detector may remain stationary while the component is moved to perform the examination.

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 digital detector array pixel that does not conform to a specified performance. Bad pixel criteria may include, but are not limited to, nonresponding, overresponding, underresponding, noisy, nonuniform, or nonpersistent, or bad neighborhood; nonpersistent bad pixels may have flickering or poor lag performance.

bad pixel map: a binary image that represents the physical locations of bad pixels on a digital detector array.

bit depth: the number of bits used to store a value.

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.

corrected image: a digital detector array image whose good pixels are offset and gain corrected and whose bad pixels have been replaced by interpolated values.

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.

gain correction: a digital detector array corrected flat field image that results from dividing nonuniformity patterns from the uncorrected flat field image.

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 format:

negative image format: the format where an object area of lesser material thickness and/or lesser material density produces a corresponding darker area on the resulting image, and where an object area of greater material thickness and/or greater material density produces a corresponding brighter area on the resulting image. For example, traditional film radiography and other techniques display a negative image format.

positive image format: the format where an object area of lesser material thickness and/or lesser material density produces a corresponding brighter area on the resulting image, and where an object area of greater material thickness and/or greater material density produces a corresponding darker area on the resulting image. For example, techniques such as radioscopy, computed radiography, digital radiography, and computed tomography may display a positive image format. Digital modalities may display a positive or negative image format.

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 (IQI):

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:

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.

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

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.

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.

offset correction: a digital detector array corrected dark image that results from subtracting dark patterns and the integrated dark signal from the uncorrected dark image.

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: see *image quality indicator (IQI)*.

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 correction: nonconforming digital detector array bad pixels at specific locations that are corrected by replacing the original pixel values with the average of the neighboring pixel values.

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.

window level: the numerical range of the displayed luminance, used to adjust the displayed brightness of an image.

window width: the numerical range of pixel values that are assigned to the range of displayed luminance, used to adjust the displayed contrast of an 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.

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 scanner: a fully mechanized scanner that, after being attached to the component, maintains an index and the offset position of the search unit. The scanner is manipulated by an independent motor controller and requires no manual handling during operation.

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 linear array search unit: a search unit that incorporates separate transmitting and receiving elements mounted on delay lines that are cut at an angle. This configuration generates beams that focus beneath the surface of the test piece, which considerably decreases the amplitude of surface reflection.

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.

even imaging mode: a total focusing method (TFM) imaging mode where the calculated mode has the same number of legs in transmission as reception, e.g., T–T and TT–TT.

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.

linear array search unit: a search unit that is made up of a set of elements, juxtaposed and aligned along an axis, that enable a beam to be moved, focused, and deflected along a plane.

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

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 (e.g., 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.

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

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

odd imaging mode: a total focusing method (TFM) imaging mode where the calculated mode does not have the same number of legs in transmission as reception, e.g., TT–T and TT–TTT.

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 wear face, 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 scanner: a manually adjustable scanner that has mechanical means to maintain an index of the search unit while maintaining the search-unit offset position, but which 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.

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.

time-of-flight diffraction (TOFD): an advanced ultrasonic technique that generally makes use of a pair of angle-beam probes, one transmitting and one receiving, to capture specular reflection, diffraction, and mode to convert responses into a meaningful TOFD display.

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. (25)

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 UV-A 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 UV-A.

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.

UV-A: 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).

UV-A intensity: a quantitative expression of ultraviolet irradiance.

(25) **I-121.4 MT — Magnetic Particle.**

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

circular magnetization: the magnetization in a part resulting from current passed directly through the part or through an internal 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.

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

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: two or more magnetic fields in different directions imposed on a part sequentially and in rapid succession, as one examination, using specialized equipment.

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.

UV-A: 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).

UV-A intensity: a quantitative expression of ultraviolet irradiance.

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.

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.

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., 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.

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): a mass flow, quantitative leakage rate measurement test in which an object under vacuum test is enclosed by a hood (permanent or temporary envelope or container) or other similar enclosure that will be filled with tracer gas to maintain the area under the hood in contact with the upstream surface of the boundary being leak tested. Alternatively, the evacuated volume may be completely enclosed by a separate volume that contains the tracer gas for the test. The permanent or temporary envelopes or containers may be flexible plastic enclosures adhered to or around a component, an annular space between concentric vessels, or an adjacent volume of a vessel that shares a boundary with an evacuated test space.

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.

$$\text{signal peak amplitude } \left(dB_{AE}\right) = \left(dB_{1\,\mu\text{V at sensor}}\right) = 2C \log_{10}\left(A_1/A_0\right)$$

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 ith and jth 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 ensure conformance to a specified level of performance or measurement accuracy. (This is usually carried out prior to, during, 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.

sizing accuracy: the difference between the manufacturer- or owner-stated dimensions of the identified flaws in the test specimen and the dimensions determined by application of the examination system on the test specimen during the qualification demonstration.

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 $1\frac{1}{2}D$ bend would have a centerline radius of $1\frac{1}{2}$ times the nominal pipe diameter. A $3D$ 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-121.12 CT – Computed Tomography Examination.

computed tomography (CT): a nondestructive examination technique that captures radiographic projections of an object at various rotational angles, which are mathematically reconstructed to produce a three-dimensional volume data set or one or more two-dimensional cross-sectional images.

representative quality indicator (RQI): an actual or similar part of comparable geometry and attenuation characteristics to the test specimen that has known measurable features, representing examples of relevant discontinuities.

scintillator: a crystalline material that converts ionizing radiation to light.

tomography: any radiologic technique that provides an image of a selected plane in an object to the relative exclusion of structures that lie outside the plane of interest.

voxel: the smallest addressable picture element in a three-dimensional digital volume, representing a value of intensity.

I-121.13 PEC – Pulsed Eddy Current. (**25**)

bending point: point in the decay curve where the graph changes from a diffusion regime to a decay regime. The bending point occurs at a characteristic time that is related to the magnetic permeability, electrical conductivity, and the wall thickness of the component.

call level: threshold on the measured wall thickness under which signals need to be assessed, and if it is determined that metal loss is indicated, the indication is to be recommended for follow-up inspection.

corrosion under fireproofing (CUF): external corrosion of piping, pressure vessels, and structural components resulting from water trapped under fireproofing.

corrosion under insulation (CUI): external corrosion of carbon steel piping, pressure vessels, and structural components resulting from water trapped under insulation.

cover: material, such as paint, plastic, asphalt, rock-wool, foam, metal mesh, cement, carbon (glass) fiber, or marine growth, that covers the surface of a tested component in the form of a layer, bundle, twine, or inlay.

decay curve: graph of the received secondary field, resulting from decay of eddy currents over time. The signal may be the voltage received on a coil or magnetic field level received with a magnetic field sensor.

excitation pulse: a magnetic pulse that is used to generate eddy currents. In common PEC examination, the magnetic field is stepped and the pulse has a block shape; other shapes are also possible.

excitation pulse duration: time for which the DC magnetic field is switched on. Eddy currents are generated at the start and end of the excitation pulse due to the sudden change in magnetic field. In most instruments, the eddy currents generated on the trailing edge of the pulse are used for measurement.

fireproofing: a systematic process, including design, material selection, and the application of materials, that provides a degree of fire resistance for protected substrates and assemblies.

follow-up examination: a second examination used to verify the presence of indications found with screening and to provide the measurement accuracy necessary for assessment of the defects found.

footprint: area affected by the magnetic field emanating from the probe. A standardized procedure for measuring the footprint can be found in Article 21, Nonmandatory Appendix A, MT-A-2152.

jacketing: the protective layer that is applied over insulation. Common jacketing materials include aluminium, stainless steel, and galvanized steel. May also be referred to as *sheathing* or *sheeting*.

lift-off: distance between the probe and the ferromagnetic object being examined.

pulsed eddy current: eddy current generated in the base material by an excitation pulse.

reference location: location that is used as a datum point compared to which relative wall thickness is reported.

screening: methodology of examination where the purpose of examination is to rapidly find the presence of defects while deemphasizing the accuracy of measurement.

MANDATORY APPENDIX II SUPPLEMENTAL PERSONNEL QUALIFICATION REQUIREMENTS FOR NDE CERTIFICATION

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.

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 and Level II practical examinations shall require at least two test specimens. These specimens shall be representative of the techniques used in the employer's written procedure or procedures, e.g., single/double wall exposure and single/double wall viewing.

(b) Each specimen shall contain a minimum of two discontinuities.

(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 (2020 edition)[1] 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 (2020 edition)[1] 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 (2020 edition)[1] 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 (2020 edition)[1] 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 ANSI/ASNT CP-105 (2020 edition) and should be used as a minimum.

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

				Experience	
Examination Method	NDE Level	Technique	Training Hours	Minimum Hours in Technique	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 previously or 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 previously or 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 previously or 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(a), from two to ten.

(a) The additional test specimens shall include varying thickness, diameter, and exposure techniques representative of those used in the employer's written procedure or procedures.

(b) The additional test specimens may be raw, unfiltered digital images provided to the individual with the radiographic technique details requiring only interpretation, evaluation, and documentation of the results.

(c) Each additional test specimen shall contain 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.

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

Table II-122.2
Minimum Ultrasonic Technique Examination Questions

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

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

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 in direct contact with the back of each film holder or cassette 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-282, or IX-282, as applicable.

T-224 SYSTEM OF IDENTIFICATION

A system shall be used to produce on each radiograph an identification that is traceable to the item being radiographed and that is permanent for the required retention period of the radiograph. This information shall include the contract, component, weld number, or part number, as appropriate. In addition, the Manufacturer's symbol or name and the date of the radiograph shall be included with the identification information on each 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 Using Industrial Radiographic Film, SE-94M/SE-94M, 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

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 calibration 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[3]

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 $3\frac{1}{2}$ 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 Using Industrial Radiographic Film, SE-94/SE-94M, may be used.

T-274.2 Geometric Unsharpness Limitations. Recommended maximum values for geometric unsharpness are as follows: (25)

Material Thickness, in. (mm)	U_g Maximum, in. (mm)
<2 (<50)	0.020 (0.51)
2 through 3 (50 through 75)	0.030 (0.76)
>3 through 4 (>75 through 100)	0.040 (1.02)
>4 (>100)	0.070 (1.78)

NOTE: Material thickness is the thickness on which the IQI is based.

T-275 LOCATION MARKERS (25)

Location markers (see Figure T-275), which shall appear as radiographic images on the radiograph, shall be placed on the part/weld, not on the film holder/cassette. Their locations shall permit the area on a radiograph to be accurately traceable to its location on the part/weld. This traceability shall be accomplished by at least one of the following:

(a) physical marking on the surface of the part/weld being radiographed, when permitted

(b) use of a weld map or part drawing

(c) use of a procedure that describes standard part or weld location marker placement

(d) any combination of (a), (b), or (c)

This traceability shall be maintained until the requirements of T-285 have been completed and for the required retention period of the radiograph, when required by the referencing Code Section.

In addition, the positions of the location markers do not limit the area of interest or the area to be interpreted. 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;

(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.

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. For wire-type IQIs, a smaller-diameter wire may be substituted for the essential wire required for any section thickness listed in Table T-276.

(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. (**25**)

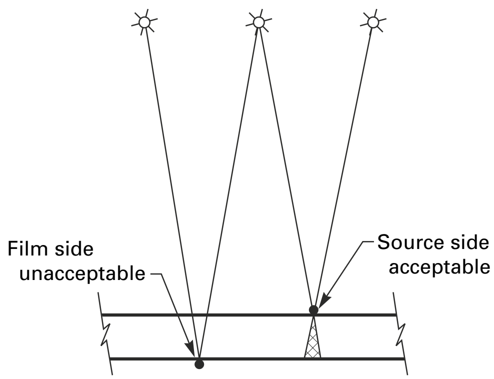
(a) Source-Side IQI(s). The IQI(s) shall be placed on the source side of the part being examined, except for the condition described in (b).

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 for hole type or SE-747 for wire type) 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.

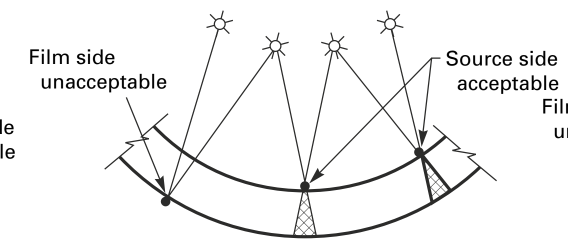
(1) The IQI on the source side of the separate block shall be placed no closer to the film than the source side of the part being radiographed.

(2) The separate block shall be placed as close as possible to the part being radiographed.

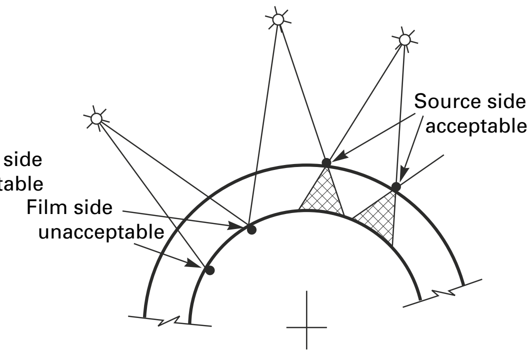
Figure T-275
Location Marker Sketches



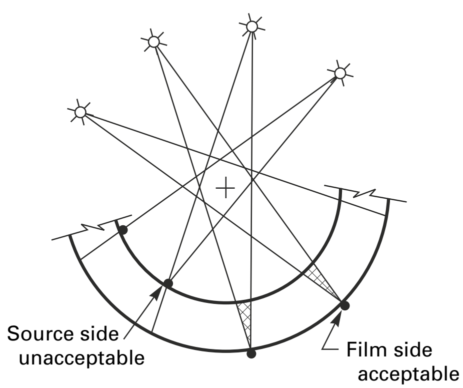
Flat component or longitudinal seam
[See T-275.1(a)(1)]
[See sketch (e) for alternate]
(a)



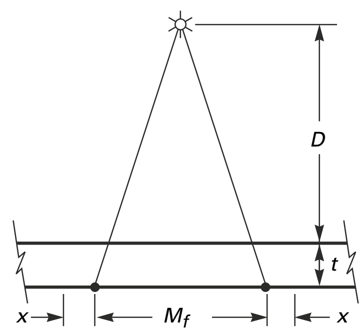
Curved components with radiation source to film distance less than radius of component
[See T-275.1(a)(2)]
(b)



Curved components with convex surface towards radiation source
[See T-275.1(a)(3)]
(c)



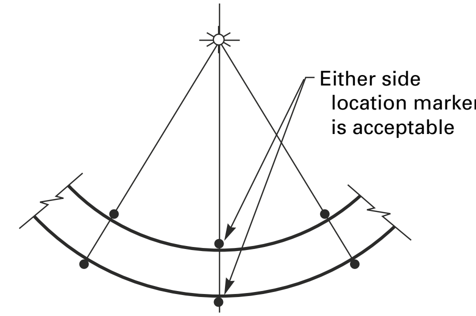
Curved components with radiation source to film distance greater than radius of curvature
[See T-275.1(b)(1)]
(d)



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 —

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
≤0.25 (≤6.4)	12	2*T*	5	10	2*T*	4
>0.25 through 0.375 (>6.4 through 9.5)	15	2*T*	6	12	2*T*	5
>0.375 through 0.50 (>9.5 through 12.7)	17	2*T*	7	15	2*T*	6
>0.50 through 0.75 (>12.7 through 19.0)	20	2*T*	8	17	2*T*	7
>0.75 through 1.00 (>19.0 through 25.4)	25	2*T*	9	20	2*T*	8
>1.00 through 1.50 (>25.4 through 38.1)	30	2*T*	10	25	2*T*	9
>1.50 through 2.00 (>38.1 through 50.8)	35	2*T*	11	30	2*T*	10
>2.00 through 2.50 (>50.8 through 63.5)	40	2*T*	12	35	2*T*	11
>2.50 through 4.00 (>63.5 through 101.6)	50	2*T*	13	40	2*T*	12
>4.00 through 6.00 (>101.6 through 152.4)	60	2*T*	14	50	2*T*	13
>6.00 through 8.00 (>152.4 through 203.2)	80	2*T*	16	60	2*T*	14
>8.00 through 10.00 (>203.2 through 254.0)	100	2*T*	17	80	2*T*	16
>10.00 through 12.00 (>254.0 through 304.8)	120	2*T*	18	100	2*T*	17
>12.00 through 16.00 (>304.8 through 406.4)	160	2*T*	20	120	2*T*	18
>16.00 through 20.00 (>406.4 through 508.0)	200	2*T*	21	160	2*T*	20

GENERAL NOTE: It is recognized that the required hole-type designation or wire-type essential wire in this table may not achieve an IQI sensitivity level of 2–2*T*. This is intentional.

(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.

(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. It is not required for the essential wire to span the full width of the weld. However, the essential wire shall span at least that portion of the weld representing the nominal single-wall material thickness and reinforcement for which the IQI essential wire was selected. The density requirements of T-282 and the sensitivity requirements of T-283 shall also be met. 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[4]

(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 (including applicable material group identification notches) 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 (including applicable material group identification notches) 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.

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.

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-284 EXCESSIVE BACKSCATTER (25)

If a light radiographic image of the lead symbol "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 radiographic image of the "B" on a lighter background is not cause for rejection. A missing radiographic image of the "B" is not cause for rejection provided the requirements of T-223 are met.

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.

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 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 in direct contact with the back of each film holder or 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 in direct contact with the back of the film holder or 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.

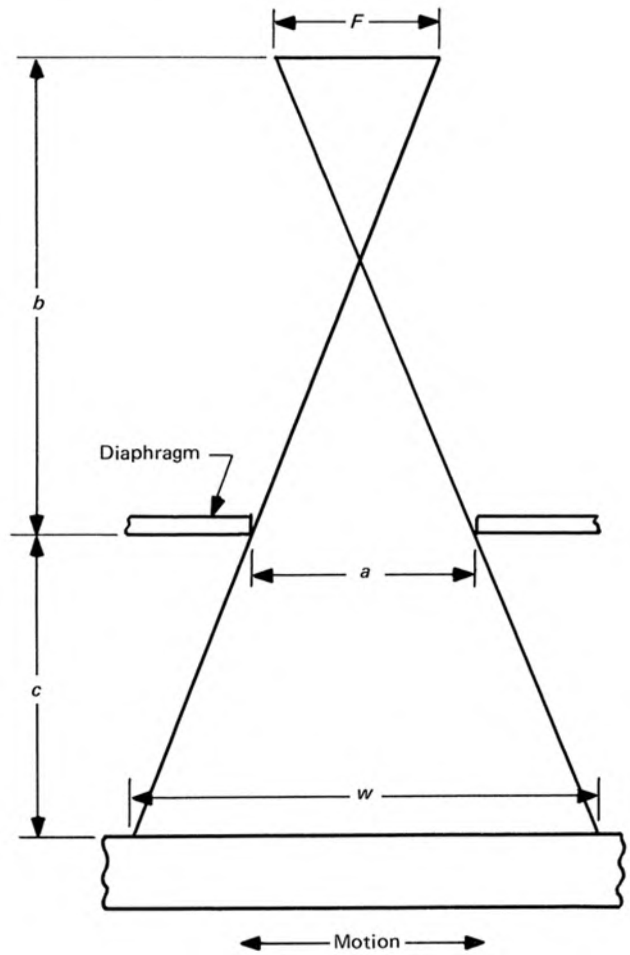
I-275 LOCATION MARKERS

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, and thereafter at approximately equal intervals not

Figure I-263
Beam Width Determination



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.

(25) II-221 PROCEDURE REQUIREMENTS

A written procedure is required and shall contain as a minimum the following (see SE-1255):

(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

(25) 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.)

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.

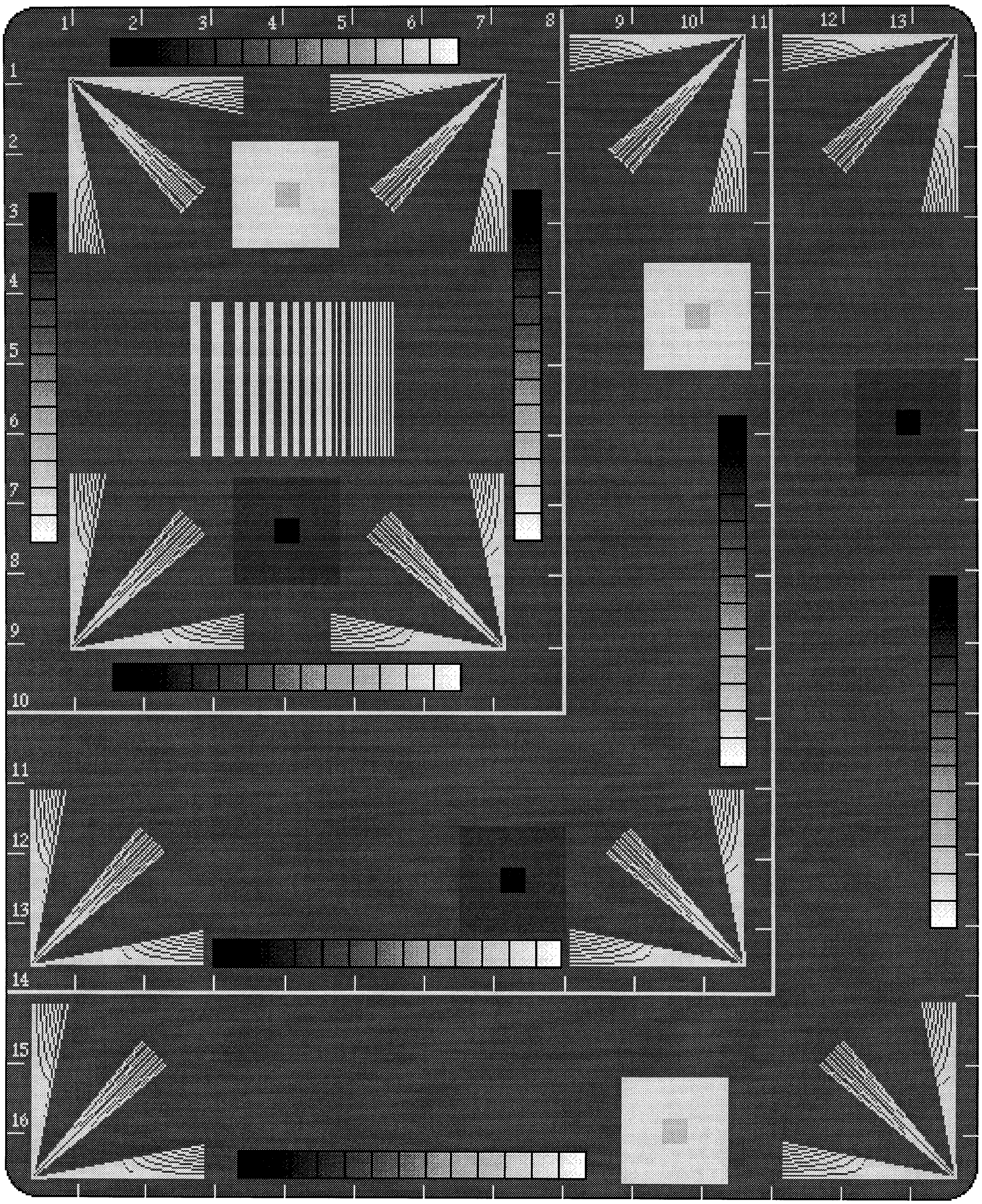
VI-A-235 SPATIAL LINEARITY TARGETS

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 $3\frac{1}{2}$ 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 $\frac{1}{4}$ 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

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.

NOTE: Sample layout and technique details are provided in SE-1030, Appendix (Nonmandatory Information) X1, Sample Radiographic Standard Shooting Sketch (RSS).

MANDATORY APPENDIX VIII RADIOGRAPHY USING PHOSPHOR IMAGING PLATE

(25) 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. SE-2007, *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

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)

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 15% 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.

(25) **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.

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 15% 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 15% are permitted in the determination of "equal to." Localized pixel averaging may be used in determining pixel intensity variations, provided the number of pixels averaged does not exceed the total number that would fit inside the area of a circle 0.125 in. (3 mm) in diameter. 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

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 (25)

For a negative image format, the requirements of T-284 shall apply. For a positive image format, if a dark radiographic image of the lead symbol "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 radiographic image of the "B" on a darker background is not cause for rejection. A missing radiographic image of the "B" is not cause for rejection provided the requirements of T-223 are met.

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

VIII-293 EMBEDDED DATA

The technique details and examination results may be embedded in the data file. When this is performed, SE-1475, Standard Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data, may be used as a guide for establishing data fields and information content. When data is embedded, the fields used shall be referenced in the procedure.

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.

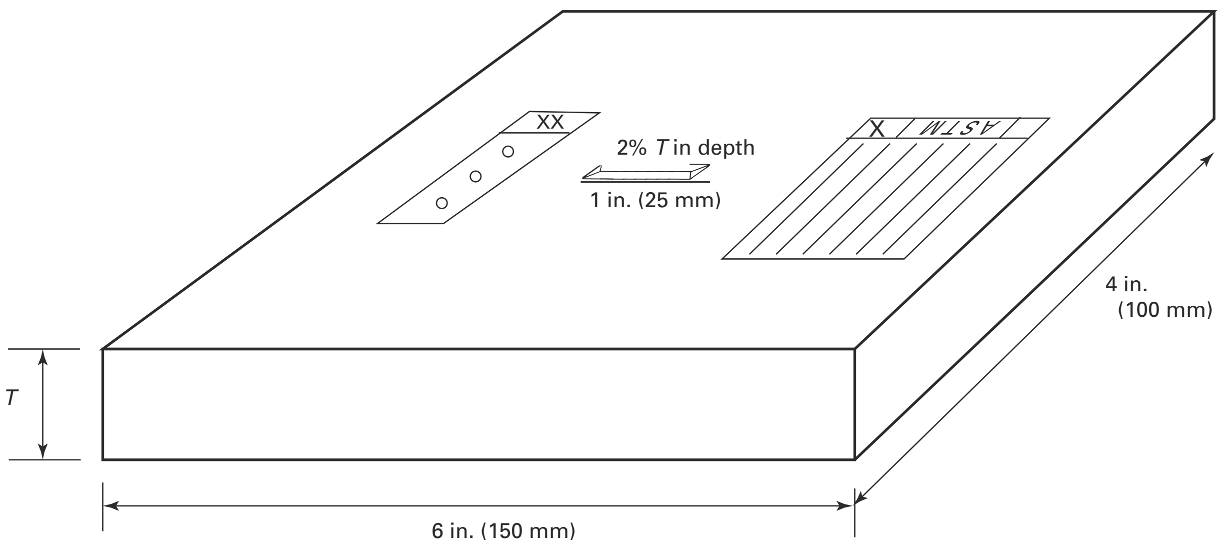
VIII-A-241 SENSITIVITY

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 = one of the following:

(1) For *T* less than or equal to 0.5 in. (13 mm), width shall be less than or equal to 2 times the notch depth.

(2) For *T* greater than 0.5 in. (13 mm) and less than or equal to 1 in. (25 mm), width shall be less than or equal to 1.5 times the notch depth.

(3) For *T* greater than 1 in. (25 mm), width shall be less than or equal to the notch depth.

length = 1 in. (25 mm) max.

(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 digital 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

(25) **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
(m) minimum pipe or component diameter to be used for bendable, flexible, or contouring detectors

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 digital radiography.

IX-230 EQUIPMENT AND MATERIALS

IX-231 FILM

The requirements of T-231 are not applicable to digital radiography.

IX-232 INTENSIFYING SCREENS

The requirements of T-232 are not applicable to digital 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 DETECTOR PIXEL CORRECTION

(a) Detector Offset Correction. Detector offset correction involves a process in which the individual pixel functionality is evaluated with no radiation applied to the detector. Each DDS procedure shall address the detailed process to be used for the specific detector being used by the DDS.

(b) Detector Gain Correction. Detector gain correction involves a process in which the individual pixel functionality is evaluated with radiation applied to the detector without the presence of an examination component or test specimen. Each DDS procedure shall address the detailed process to be used for the specific detector being used by the DDS.

(c) Detector Correction Frequency. Each detector shall undergo both an offset and gain correction prior to the beginning of the examination evolution. During the examination evolution, one or both of the corrections may need to be repeated to maintain image quality.

Each DDS procedure shall clearly describe the recommendations and requirements for performing detector corrections during an examination evolution.

IX-261 BAD PIXEL MAPS

(a) Digital detectors shall be supplied with the detector manufacturer's original bad pixel map, including the process and methodology used by the manufacturer to develop the bad pixel map.

(b) In addition, DDS software shall have the capability to assess the detector's flat field image with offset and gain corrections applied. The software shall also have the ability to update the original bad pixel map on demand.

(c) At the completion of each examination evolution or 24 hr of continuous examination, the DDS software shall be used to provide a current bad pixel map for the detector. This map shall be capable of providing a direct one-to-one overlay of any image of the examination evolution.

(d) This current bad pixel map shall be used to ensure that no relevant indication could have been masked during the examination evolution.

IX-262 DENSITOMETER AND STEP WEDGE COMPARISON FILM

The requirements of T-262 are not applicable to digital radiography.

IX-263 BEAM WIDTH

When a change in the 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 MOTION UNSHARPNESS

IX-274.1 Geometric Unsharpness. Recommended geometric unsharpness shall be determined in accordance with T-274.1.

IX-274.2 Motion Unsharpness. 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
U_M = 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

IX-275 LOCATION MARKERS

(a) When encoders are used for automated examination techniques, 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

IX-277.1 Placement of IQIs.

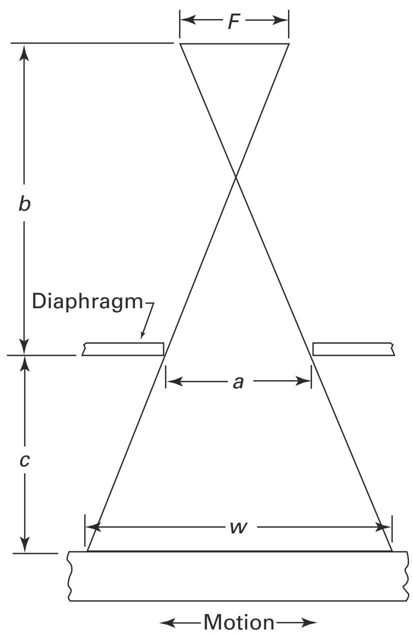
(a) Source-Side IQI(s). When using separate blocks for IQI placement as described in T-277.1(a), the thickness of the blocks shall be such that the image brightness at the body of the IQI is judged to be equal to or greater than the image brightness at the area of interest for a negative image format. If verified by measurement, pixel intensity variations up to 30% 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 automated examination 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 automated examination 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 automated examination 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.

Figure IX-263
Beam Width Determination



(e) It is not required for the essential wire to span the full width of the weld. However, the essential wire shall span at least that portion of the weld representing the nominal single-wall material thickness and reinforcement for which the IQI essential wire was selected. The image brightness requirements of IX-282 and the sensitivity requirements of IX-283 shall also be met.

(f) 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 30% 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

The bad pixel map, as described in IX-261, shall be viewed as an overlay of each associated image to verify that the region of interest is free of a sufficient number or orientation of bad pixels that could mask a defect.

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 30% are permitted in the determination of "equal to." Localized pixel averaging may be used in determining pixel intensity variations, provided the number of pixels averaged does not exceed the total number that would fit inside the area of a circle 0.125 in. (3 mm) in diameter. This image brightness requirement is reversed for a positive image format. Additionally, the requirements of T-282 are not applicable to digital 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.

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.

(25) ## IX-284 EXCESSIVE BACKSCATTER

For a negative image format, the requirements of T-284 shall apply. For a positive image format, if a dark radiographic image of the lead symbol "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 radiographic image of the "B" on a darker background is not cause for rejection. A missing radiographic image of the "B" is not cause for rejection provided the requirements of T-223 are met.

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) bad pixel maps as described in IX-261(c)
(r) computer monitor resolution

IX-293 EMBEDDED DATA

The technique details and examination results may be embedded in the data file. When this is performed, SE-1475, Standard Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data, may be used as a guide for establishing data fields and information content. When data is embedded, the fields used shall be referenced in the procedure.

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

(25) IX-A-221 DEMONSTRATION BLOCK

IX-A-221.1 Flat Detectors. 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.

IX-A-221.2 Nonflat Detectors. For procedures using bendable, flexible, or contouring detectors, the procedure shall also be demonstrated using a block in accordance with Figure IX-A-221.2-1. This block shall be of material that is radiographically similar to the material described in the procedure and shall be in accordance with the smallest diameter limitation described in IX-221.1(m).

For automated examination techniques, 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.

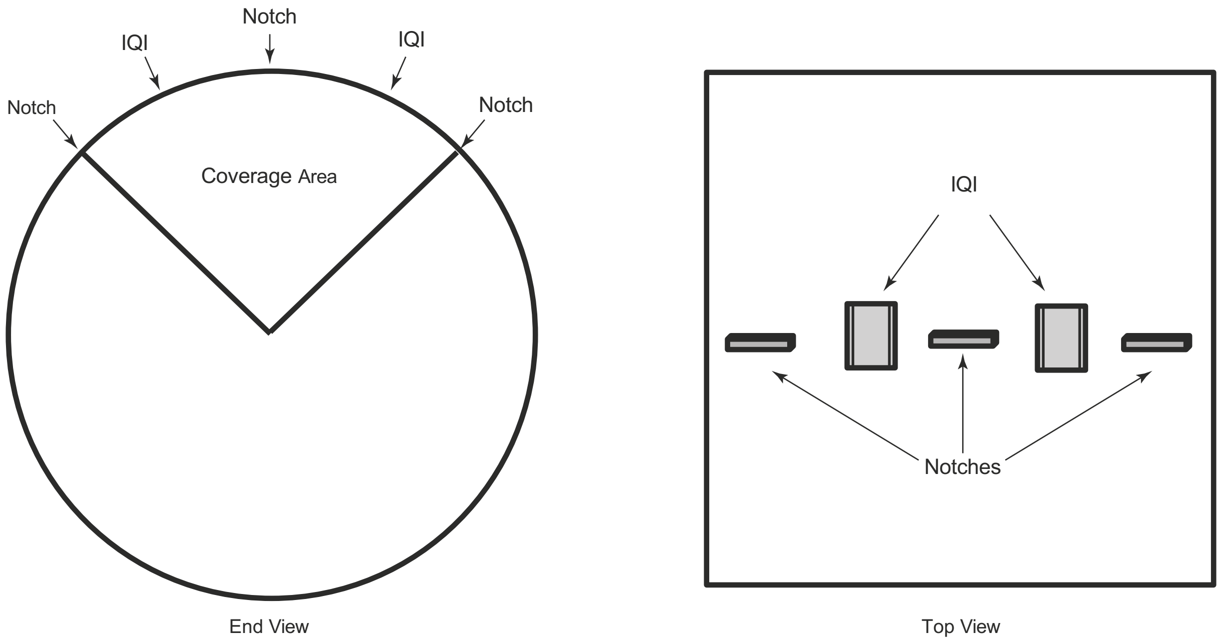
IX-A-241 SENSITIVITY

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.

Figure IX-A-221.2-1
Procedure Demonstration Block for Nonflat Detectors



GENERAL NOTES:

(a) Hole-type and wire-type IQIs shall be selected as appropriate for *T* from Table T-276.

(b) Notch depth shall be 2% of *T*. Notch depth need not be less than 0.005 in. (0.13 mm).

(c) Notch dimensions shall be as follows:

(1) depth = 1.6%*T* to 2.2%*T*

(2) width = one of the following:

(a) For $T \leq 0.5$ in. (13 mm), width shall be ≤2 times the notch depth.

(b) For $T > 0.5$ in. (13 mm) and ≤1 in. (25 mm), width shall be ≤1.5 times the notch depth.

(c) For $T > 1$ in. (25 mm), width shall be less than or equal to the notch depth.

(3) length = 1 in. (25 mm) max.

NONMANDATORY APPENDIX A RECOMMENDED RADIOGRAPHIC TECHNIQUE SKETCHES FOR PIPE OR TUBE WELDS

(25) A-210 SCOPE

The sketches in Tables 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.

Table A-210-1
Single-Wall Radiographic Techniques

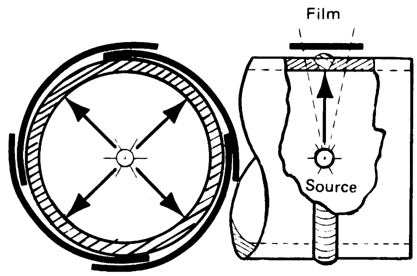
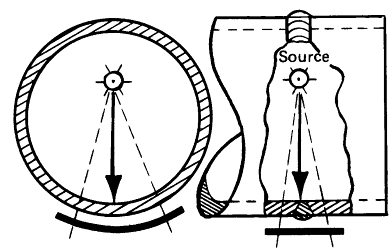
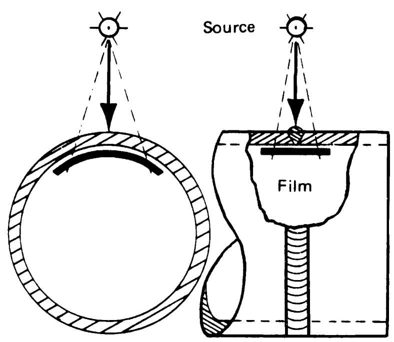
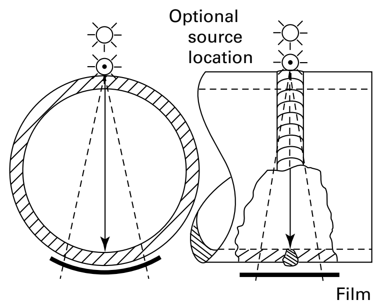
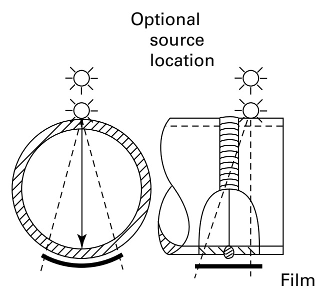
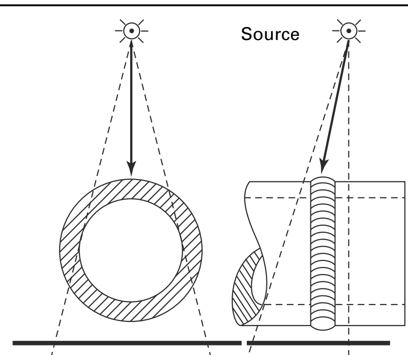
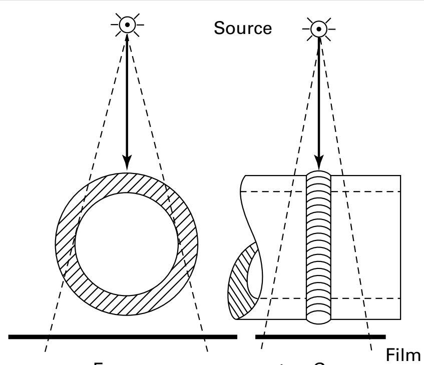
Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement: End View / Side View	IQI Selection	IQI Placement	Location Marker Placement
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — A	T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Either Side T-275.3 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)

Table A-210-2
Double-Wall Radiographic Techniques

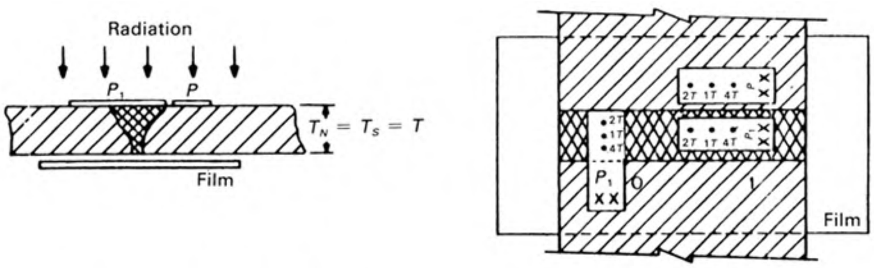
O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Double- Wall: T-271.2(a) at Least 3 Exposures 120 deg to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — D		T-276 and Table T-276	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)
$3^1/_2$ 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
$3^1/_2$ 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

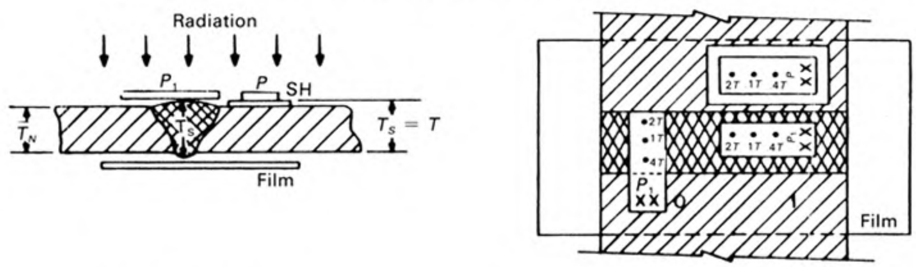
C-210 SCOPE

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.

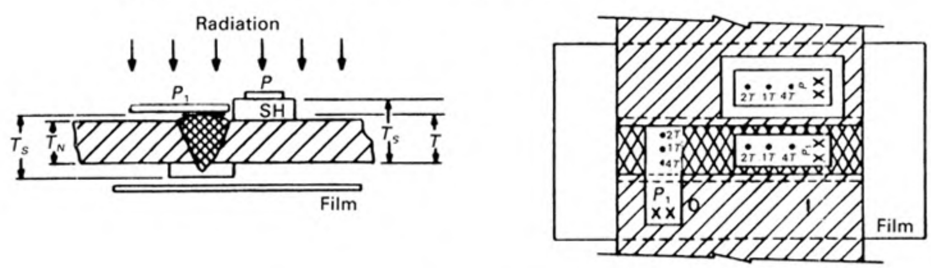
Figure C-210-1
Side and Top Views of Hole-Type IQI Placements



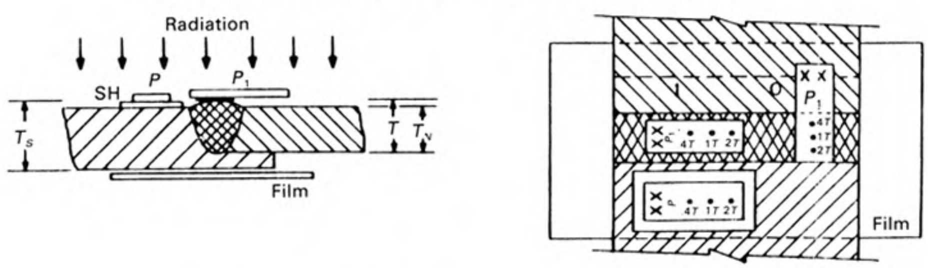
(a) Single Wall, No Reinforcement, No Back-Up Strip



(b) Single Wall, Weld Reinforcement, No Back-Up Strip



(c) Single Wall, Weld Reinforcement, Back-Up Strip



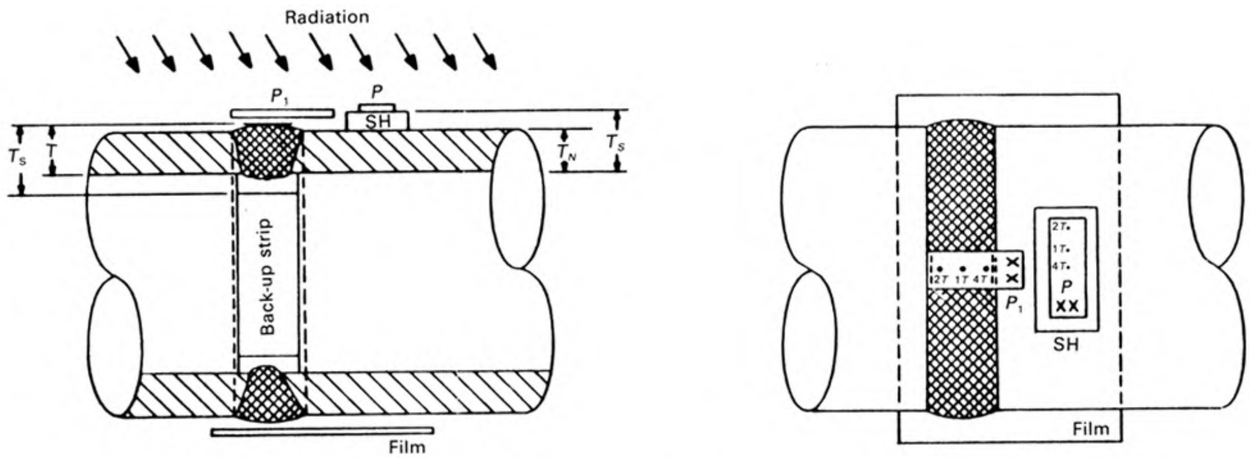
(d) Single Wall, Integral Backing Ring, Weld Reinforcement

Legend:

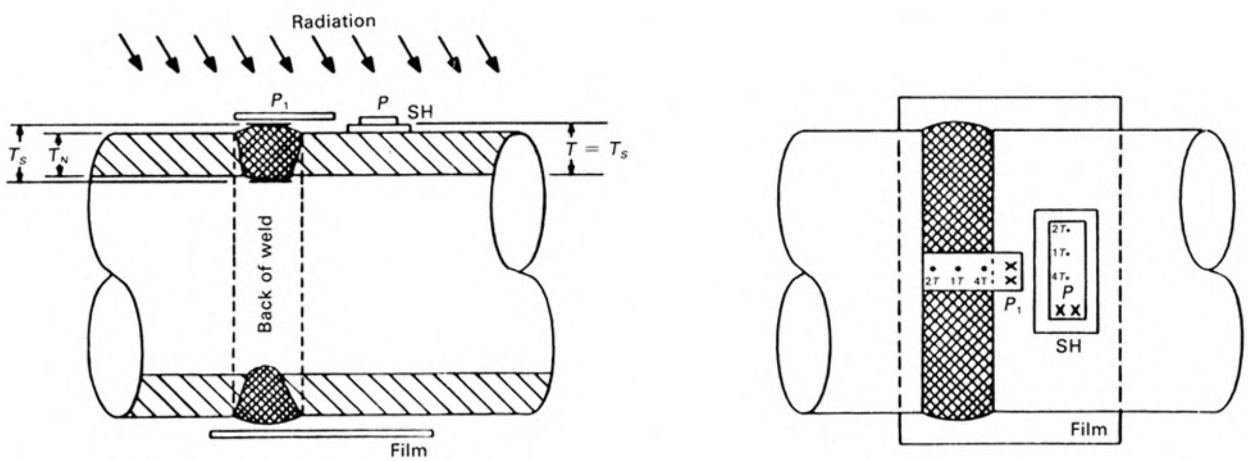
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

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:

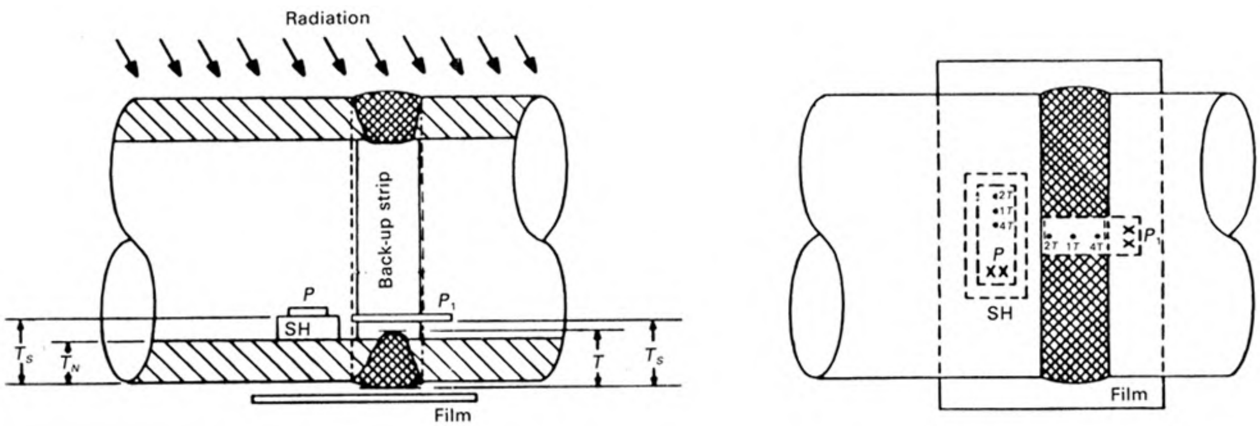
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

GENERAL NOTES:

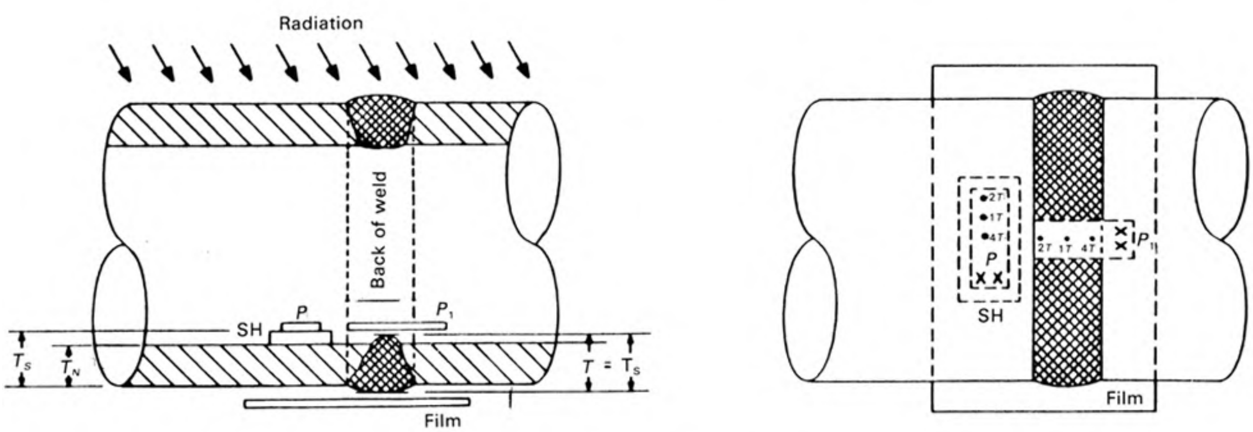
(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

(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



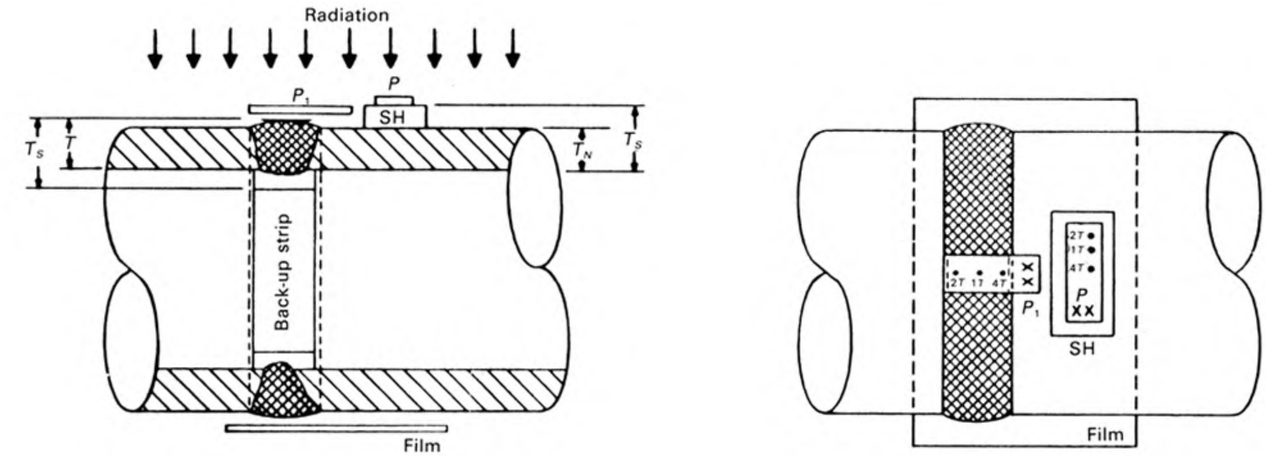
(b) Double-Wall Technique, Single-Wall Viewing, Wall Reinforcement, No Back-Up Strip

Legend:

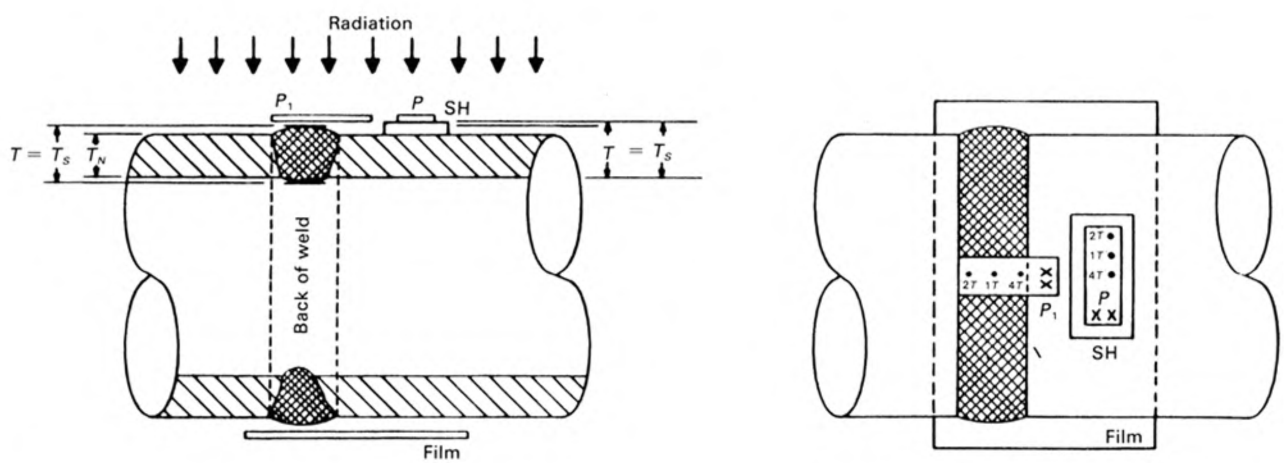
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

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

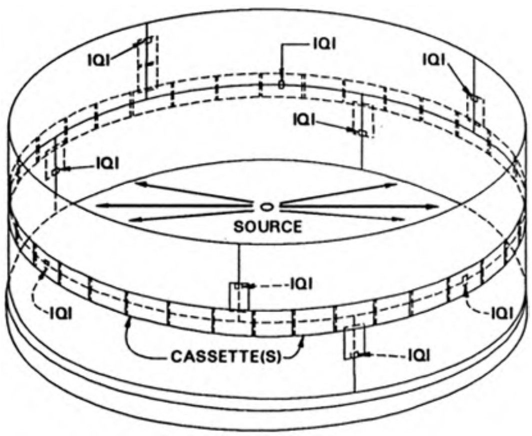
GENERAL NOTES:
(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.
(b) IQI is based on the single-wall thickness plus reinforcement.

NONMANDATORY APPENDIX D
NUMBER OF IQIS (SPECIAL CASES)

D-210 SCOPE

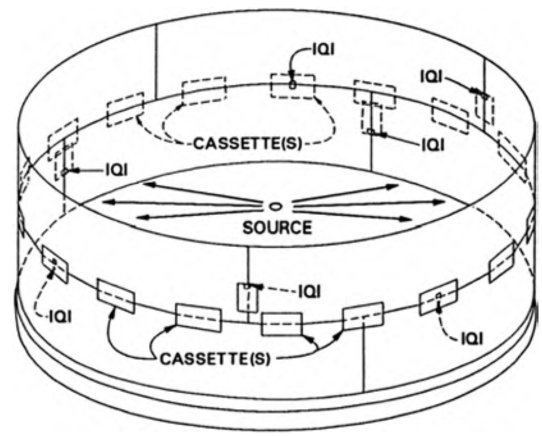
Figures D-210-1 through D-210-8 of this Appendix illustrate examples of the number and placement of IQIs that may be used in the special cases described in T-277.2(b). These figures are not intended to cover all configurations or applications of production radiography.

Figure D-210-1
Complete Circumference Cylindrical Component



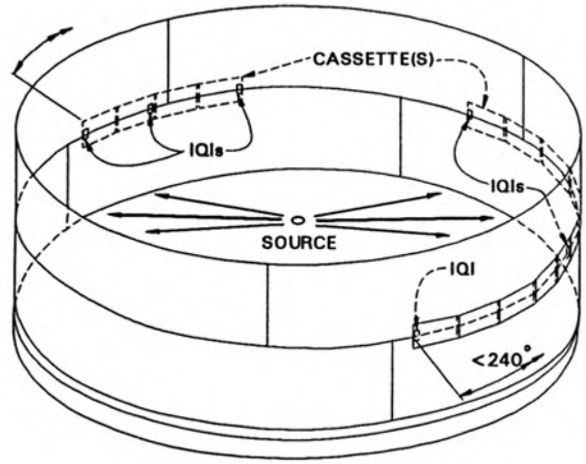
GENERAL NOTE: See T-277.2(b)(1)(-a) and T-277.2(b)(3).

Figure D-210-2
Section of Circumference 240 deg or More Cylindrical Component (Example is Alternate Intervals)



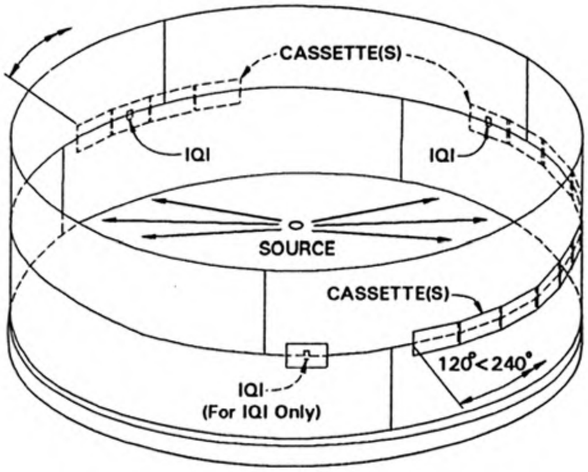
GENERAL NOTE: See T-277.2(b)(1)(-b) and T-277.2(b)(3).

Figure D-210-3
Section(s) of Circumference Less Than 240 deg Cylindrical Component



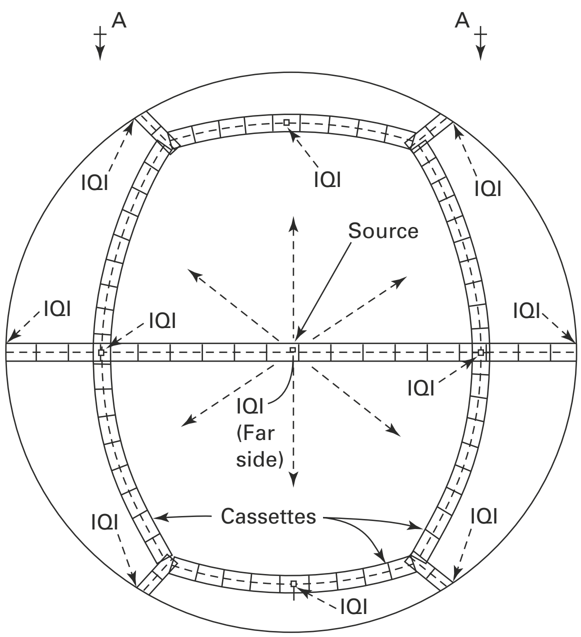
GENERAL NOTE: See T-277.2(b)(2)(-b).

Figure D-210-4
Section(s) of Circumference Equal to or More Than 120 deg and Less Than 240 deg Cylindrical Component Option



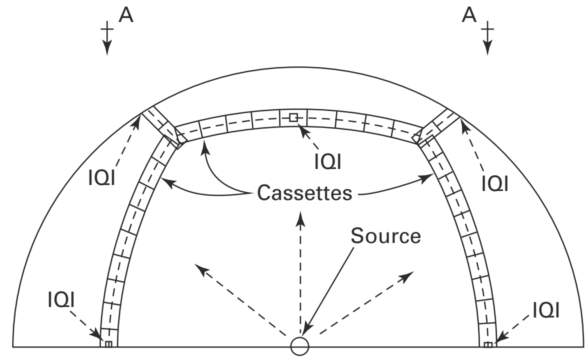
GENERAL NOTE: See T-277.2(b)(2)(-b).

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

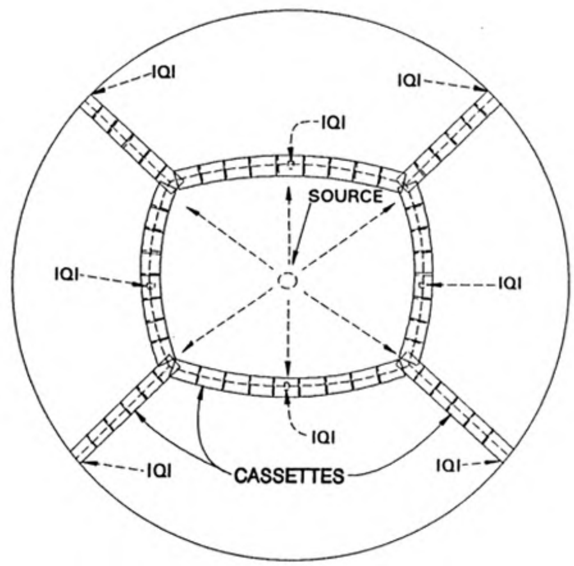
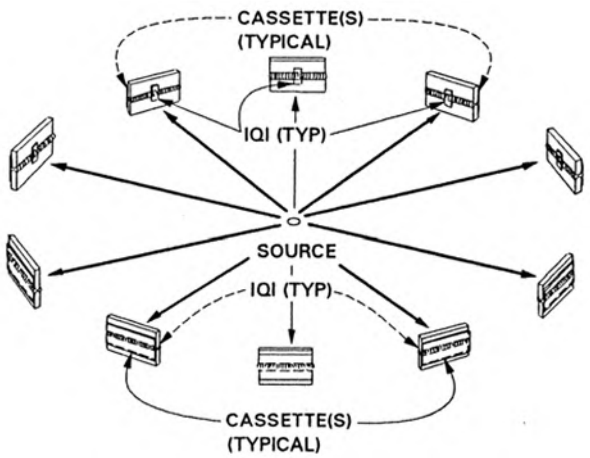


Figure D-210-8
Array of Objects in a Circle



GENERAL NOTES:
(a) Special cases IQI locations are typical in all figures.
(b) See T-277.2(b)(8).

ARTICLE 3 FULL MATRIX CAPTURE (25)

T-310 SCOPE

This Article 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 Nonmandatory Appendix A.

When this Article is specified by a referencing Code Section, the ultrasonic method described in this Article shall be used together with Article 1.

Terms used in this Article are defined in Article 1, Mandatory Appendix I, I-121.2.

This Article provides or references requirements for weld examinations, which are to be used in selecting and developing FMC ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures shall be used for the FMC ultrasonic examination of welds and the dimensioning of indications for comparison with acceptance standards when required by the referencing Code Section. Additionally, the referencing Code Section shall be consulted for specific requirements for the following:

(a) personnel qualification and certification requirements
(b) demonstration, qualification, and acceptance of procedure requirements
(c) examination system characteristics
(d) retention and control of calibration blocks
(e) extent of examination or volume to be scanned or both
(f) acceptance standards
(g) retention of records
(h) report requirements

T-320 GENERAL

For specific applications or techniques, refer to the specific referencing documents and the following:

(a) T-351 for special provisions for coarse-grain materials and welds
(b) T-352 for special provisions for computerized imaging techniques

T-321 WRITTEN PROCEDURE REQUIREMENTS

T-321.1 Requirements. The examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-321.1-1.

Due to unique processes or equipment, essential variables that are not identified in Table T-321.1-1 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.

T-321.1.1 Software. Software revisions shall not require requalification unless any change has been made that would influence the ultrasonic signal as displayed, recorded, or automatically processed. Software revisions shall be documented and available for review.

T-321.2 Procedure Qualification. Procedure qualification is required per Mandatory Appendix I and shall comply with Article 1, T-150(d). The requirements of Table T-321.1-1 shall apply. Any change of a requirement in Table T-321.1-1 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 or scan plan, as applicable.

T-321.2.1 Flaw Location. In addition to the flaws described in Mandatory Appendix I, I-335.5(a)(1) and IX-435.5(b), the subsurface flaw described in Mandatory Appendix I, I-335.5(a)(3) shall be replaced with a subsurface planar flaw inserted along the face of the weld bevel and within the same angle tolerances of the production bevel angle, unless specified otherwise by the referencing Code Section. For joint designs with more than one bevel angle (e.g., compound, double-V, and J-groove), a subsurface planar flaw shall be inserted at an angle normal to the exam surface at the centerline of the weld. All flaw placements shall maintain a minimum separation distance of 1 in. (25 mm) from any edge of the block.

Table T-321.1-1
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 (straight beam, angle beam, contact, and/or immersion)	X	...
Calibration (calibration blocks and techniques)	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 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

T-322 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 modes, 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.

T-323 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 postprocessed images, or who 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.

T-330 EQUIPMENT

T-331 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.

T-332 SEARCH UNITS

Search units used for examination shall be the same (i.e., manufacturer, model number, and physical configuration, including wedges) as those used during qualification.

T-332.1 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 ensure adequate penetration or better resolution. Search units with contoured contact wedges may be required to aid ultrasonic coupling per T-332.2. If a contoured wedge is used for examination, the calibration block diameter shall also be suitable for the selected wedge curvature range in T-332.2(b)(1) or T-332.2(b)(2).

T-332.2 Contact Wedges. When required by (a) below, examinations performed on a curved component shall be performed using a contoured wedge, to ensure sufficient ultrasonic coupling is achieved and to limit any potential rocking of the wedge as it is moved along the circumference of the component.

(a) Wedges shall be contoured if the component diameter to be examined is equal to or less than D using the following calculation:

$$D \leq \left[\frac{(A^2)}{0.113\ \text{in.}\ (2.87\ \text{mm})} \right]$$

where

A = length of the wedge footprint during circumferential scanning or the width when scanning in the axial direction, in. (mm)
D = component diameter at the examination surface (I.D./O.D.), in. (mm)

The footprint is defined as the physical dimension of the wedge in the curved direction of the component.

(b) When contouring is required per (a) above, the wedge contour dimension shall be selected from the tables in (1) or (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 the O.D.

Actual Component Outside Diameter, in. (mm)	Allowable Increase in Contour Diameter Over Component O.D., in. (mm)
<4 (<100)	−0 to +1 (+25)
≥4 to <10 (≥100 to <250)	−0 to +2 (+50)
≥10 to <18 (≥250 to <455)	−0 to +4 (+100)
≥18 to <23 (≥455 to <580)	−0 to +6 (+150)
≥23 (≥580)	−0 to +10 (+250)

(2) Minimum contour for examinations performed from the I.D.

Actual Component Inside Diameter, in. (mm)	Allowable Decrease in Contour Diameter Under Component I.D., in. (mm)
<4 (<100)	+0 to −1 (−25)
≥4 to <10 (≥100 to <250)	+0 to −2 (−50)
≥10 to <18 (≥250 to <455)	+0 to −4 (−100)
≥18 to <23 (≥455 to <580)	+0 to −6 (−150)
≥23 (≥580)	+0 to −10 (−250)

T-332.3 Search-Unit Performance. The amplitude response from all individual elements within the aperture shall fall within 3 dB. Elements outside this parameter shall be considered inactive. The number of inactive elements within an aperture shall not exceed 1 element for every 16 elements, with no 2 inactive elements being adjacent. Exceptions to these requirements shall be demonstrated and documented during the qualification.

T-333 COUPLANT

T-333.1 General. The couplant, including additives, shall not be detrimental to the material being examined.

T-333.2 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-334 CALIBRATION BLOCKS

T-334.1 General. A calibration block meeting the requirements of Figure T-334.1-1 shall be used and shall also meet the requirements of T-334.1.2 through T-334.1.6.

Alternatively, existing calibration blocks (e.g., described in Article 4, T-434) may be used, provided one of the following applies:

(a) Notch, slot, and side-drilled holes (SDHs) meeting the requirements of Figure T-334.1-1 are embedded.

(b) Notch and slot reflectors meeting the requirements of Figure T-334.1-1 are embedded and a known reference standard described in T-335 with SDHs meeting the requirements of T-362.8.1 is used.

Blocks may be flat or curved.

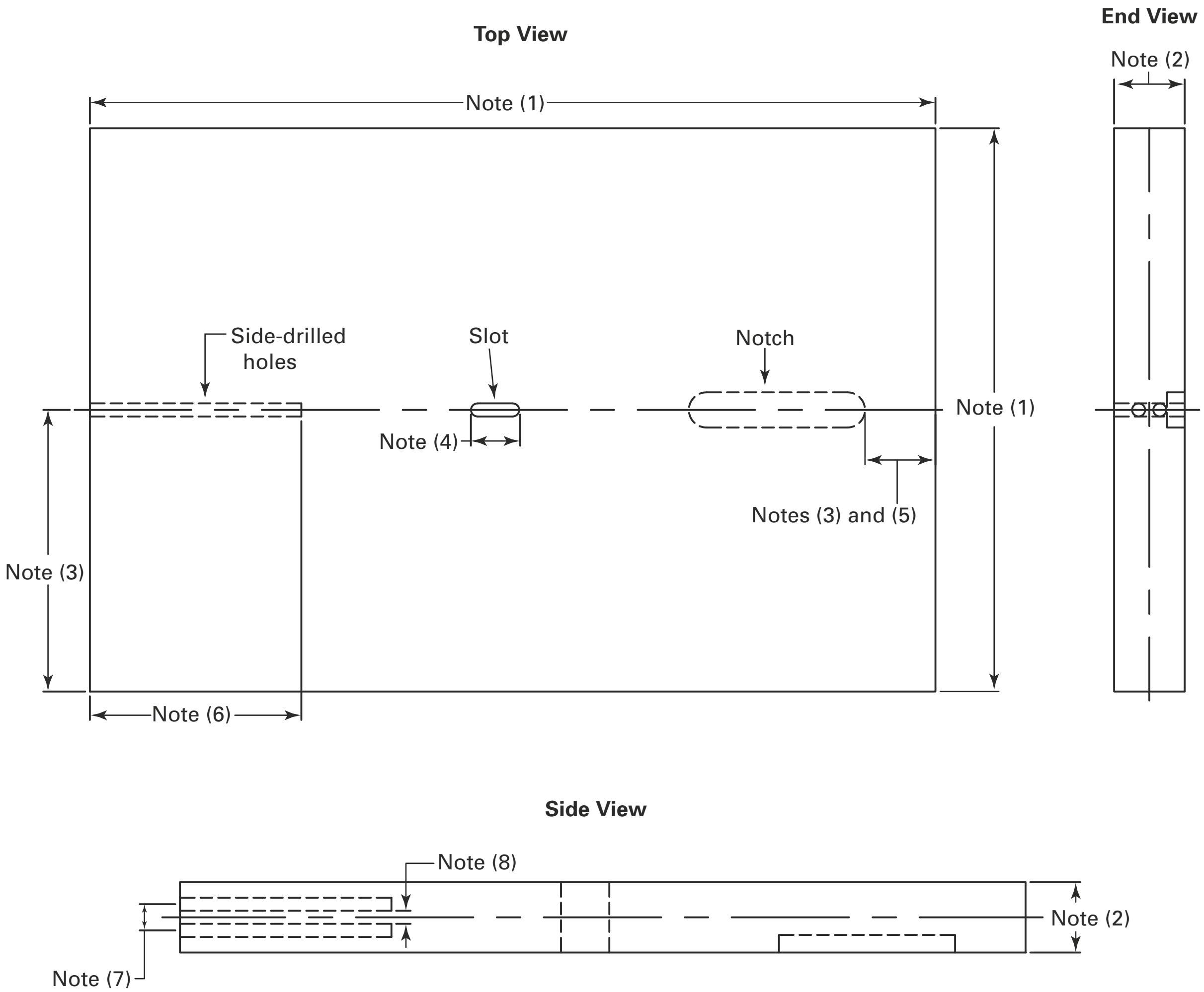
T-334.1.1 Additional Reflectors. Additional reflectors (e.g., SDHs) may be installed, provided

(a) they are not used in lieu of the required reflectors

(b) they do not interfere with the ultrasonic response from the required reflectors

(c) a description of the additional reflectors and of their intended purpose is in the written procedure

Figure T-334.1-1
Calibration Block



Weld Thickness, t, in. (mm)	Maximum Hole Diameter, in. (mm)
≤1 (≤25)	$^3/_{32}$ (2.5)
>1 to 2 (>25 to 50)	$^1/_8$ (3)
>2 to 4 (>50 to 100)	$^3/_{16}$ (5)
>4 (>100)	[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 T-334.1-1
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).

T-334.1.2 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. The process for performing transfer correction shall be documented in the procedure.

T-334.1.3 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-334.1.4 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 ±$^1/_8$ 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 from the adjoining parent materials, where it is a factor during the examination, the calibration block shall be designed to be representative of this combination.

T-334.1.5 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-334.1.6 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-335 REFERENCE STANDARDS

Known reference standards (e.g., IIW, IIW PA Block Type A, SE-2491, ISO 19675, calibration block of T-334.1) shall be used to verify instrument range, velocity, and delay settings.

T-340 MISCELLANEOUS REQUIREMENTS

T-341 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 or vibratooling or both 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 centerline and designation of regular intervals along the length of the weld. Any system may be used provided it meets the requirements in (a) and (b).

T-350 TECHNIQUES

Contact or immersion techniques may be used.

T-351 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. For the purposes of this paragraph, "high alloy steel" is defined as all stainless steels and any other alloy steel in which the sum of all elements, other than iron, exceeds 10% of its weight. Difficulties with ultrasonic examinations can be caused by an inherently coarse-grained or 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 or supplement the provisions of this Article in accordance with Article 1, T-150(b) when examining such welds in these materials.

Additional items, which are required, are weld mockups with reference reflectors in the weld deposit and search units producing refracted longitudinal waves.

T-352 DATA RECONSTRUCTION TECHNIQUES

Algorithms used to generate imaging modes 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 modes were included in the calibration prior to the exam

T-353 SCANNING TECHNIQUES

Examination may be performed by one of the following techniques:

(a) manual scanning using no scanner equipment

(b) nonautomated scanning using nonautomated scanners

(c) semiautomated scanning using semiautomated scanners

(d) automated scanning using automated scanners

T-360 CALIBRATION

T-361 INSTRUMENT CALIBRATION

An instrument calibration shall be performed per the instrument manufacturer's operation and maintenance manual at intervals not to exceed 1 yr, or prior to the first use thereafter.

T-362 GENERAL CALIBRATION REQUIREMENTS

T-362.1 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.

Amplitude fidelity shall be preserved to 2 dB or less. The process for determining amplitude fidelity shall be included in the qualified procedure.

T-362.2 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-362.3 Couplant. The same couplant to be used during the examination shall be used for calibration.

T-362.4 Contact Wedges. When contoured wedges are required by T-332.2, a curved calibration block shall be used.

Alternatively, for calibration, one or more flat wedges 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.

(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 tolerances.

(c) The flat wedges shall not be used for examination.

(d) Verification prior to the examination shall be performed with the contoured wedge to be used for the examination. The verification shall use an identical reflector established in T-364, in a suitably curved block [i.e., within the component curvature contour selection criteria established from T-332.2(b)(1) or T-332.2(b)(2)] and shall fall within 10% of amplitude and material depth.

T-362.5 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.

T-362.6 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-362.7 Distance–Amplitude Correction (DAC). Correction for attenuation, e.g., DAC or time-corrected gain (TCG), is not required.

T-362.8 Performance Verification. Prior to examination, the system shall be verified as described in T-362.8.1 through T-362.8.3.

T-362.8.1 Resolution Verification. System resolution shall be considered satisfactory on 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 T-335 (e.g., IIW PA Block Type A, SE-2491) may be used provided that the depth of the holes falls within the middle third of the examination volume.

T-362.8.2 Modes Verification. The search units shall be placed using the stand-off distances as depicted in the scan plan such that the corresponding reflectors for both (a) and (b) below are imaged at a distance beyond the centerline of the weld.

When using opposing tandem search units, the opposing search units shall be placed, as depicted by the scan plan, on either side of the reflectors such that the reflector's position would be imaged equidistant from the search units and on the weld centerline.

All reflectors within the calibration block shall be detected by a minimum of two different imaging modes. Image amplitude of all calibration reflectors, or of the relevant portion of calibration reflectors, shall be greater than 12 dB above the background noise level.

(a) For verification of even imaging modes, the SDHs and notch in the calibration block shall be imaged in those areas of the through-wall thickness of the calibration block to the extent required to obtain volumetric coverage as depicted by the scan plan.

(b) For verification of odd imaging modes, the through-wall slot in the calibration block shall be imaged in those areas of the through-wall thickness of the calibration block to the extent required to obtain volumetric coverage as depicted by the scan plan.

T-362.8.3 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% of the known height or 0.150 in. (4 mm) and shall not exceed 50% of the known length.

T-363 SYSTEM CALIBRATION FOR NON-DISTANCE–AMPLITUDE TECHNIQUES

Calibration includes all those actions required to ensure 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 calibration blocks with artificial or discontinuity reflectors.

Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-364 CALIBRATION SENSITIVITY

Calibration sensitivity shall be established by recording the imaged intensity of an SDH described in T-362.8.1 to a level greater than or equal to 50% full screen height (FSH) and shall not exhibit saturation. Other reflectors (i.e., entry surface, back wall) may exhibit saturation.

T-367 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.

T-367.1 Equipment Confirmation Checks. The examination system shall be verified for compliance with T-332.3 and T-362.1 prior to initial calibration and at the conclusion of an examination or series of examinations.

T-367.2 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 of T-367.3.

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-367.2.1 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), or electronic simulation. However, the simulation used shall be identifiable on the calibration sheet.

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 3 months, whichever is less.

T-367.3 Confirmation Acceptance Values.

T-367.3.1 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 rerecorded.

T-367.3.2 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 rerecorded.

T-370 EXAMINATION

T-371 GENERAL EXAMINATION REQUIREMENTS

T-371.1 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.

T-371.1.1 Image Modes. The imaging modes used during calibration shall be the same as those for the examination.

T-371.2 FMC Frame. To fulfill the amplitude fidelity requirement in T-362.1, the frame shall have enough temporal range to encompass the examination volume and density when combined with the reconstruction process.

T-371.3 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 minimum overlap of 10% of the frame width shall be maintained.

T-371.4 Non-Distance–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-371.5 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-371.6 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

T-372 SCANNING DIRECTION

T-372.1 Reflectors Parallel to the Weld Seam. The FMC frame 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-372.2 Reflectors Transverse to the Weld Seam. Alternative ultrasonic techniques may be performed for reflectors transverse to the weld axis.

(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-372.3 Single-Sided Access Welds. Welds that cannot be fully examined from two directions per T-372.1 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 areas of single-sided access and, if applicable, the extent of the limit coverage shall be noted in the examination report.

T-372.4 Inaccessible Welds. Welds that cannot be examined from at least one side (edge) using the FMC 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-373 WELD METAL OVERLAY CLADDING TECHNIQUES

The techniques described in this paragraph 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, the cladding shall be examined from the clad surface.

When examination for lack of bond only is required, the examination may be performed from the weld metal overlay clad or unclad surface.

T-374 NON-DISTANCE–AMPLITUDE TECHNIQUES

The number of modes 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-374.1 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., back wall) and the upper and lower limits of the sensitivity range are qualified. The process for this qualification shall be included in the procedure.

T-375 NOZZLE SIDE WELD FUSION ZONE AND ADJACENT NOZZLE PARENT METAL

T-375.1 Search-Unit Location. When the referencing Code Section specifies that an ultrasonic examination be performed to examine either the nozzle side weld fusion zone or the adjacent nozzle parent metal, a straight beam examination shall be conducted from the inside nozzle surface.

T-375.2 Examination. The general examination requirements of T-371 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 units may be moved either circumferentially around or axially across the examination zone. The FMC frame 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-377 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-380 EVALUATION

T-381 GENERAL EVALUATION REQUIREMENTS

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. These may appear as spot or line indications. Other 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 [e.g., internal attachment, 200% amplitude, 1 in. (25 mm) above weld centerline, 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 or image 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-381.1 Imaging Modes. Imaging modes identified in T-362.8.2 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.

T-381.1.1 Direct Modes. Direct imaging modes (i.e., L–L or T–T) alone shall not be considered adequate for full volume examination.

T-381.1.2 Data Density. The spatial resolution of data points within the imaged grid (i.e., pixel spacing and nodes) shall comply with T-362.1. Spatial resolution within the grid shall not be greater than that used during qualification.

T-381.2 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.

T-381.3 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 each artifact shall be made.

T-382 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 $1\frac{1}{2}$ in. (38 mm) thick

(b) 0.20 in. (5 mm) for welds in material greater than $1\frac{1}{2}$ in. (38 mm) thick but less than 4 in. (100 mm) thick

(c) $0.05T$ or $\frac{3}{4}$ 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.

T-383 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 (see T-393).

T-384 ALTERNATIVE EVALUATIONS

Reflector dimensions exceeding the referencing Code Section requirements may be evaluated to any alternative standards provided by the referencing Code Section.

T-385 EVALUATION SETTINGS

Final flaw evaluation shall only be made after all display parameter adjustments have been completed.

T-386 SIZE AND CATEGORY

T-386.1 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.

T-386.2 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.

T-388 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 1, this Article, and the referencing Code Section. Acceptance shall be completed prior to presentation of the scan data and accompanying documentation to the Inspector.

T-390 DOCUMENTATION

T-391 RECORDING INDICATIONS

T-391.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-391.2 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.

T-392 EXAMINATION RECORDS

For each FMC examination, the requirements of Article 1, T-150(d) and Article 1, T-190(a); Article 4, 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 nonintegral wedges, the description shall include x and y dimensions

(d) the brand name or type of couplant used

(e) the type and length of the search-unit cables used

(f) the scanner type (per T-353) and the adhering and guiding mechanism

(g) identification of all examination-related computerized programs including software revisions

(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 settings

(k) calibration data (including reference reflector) and responses for resolution, modes, sizing, and sensitivity

(l) data correlating simulation blocks and electronic simulators, 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], 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 modes 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) surfaces 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 techniques 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.

T-393 REPORT

A report of the examinations shall be made. The report shall include those records indicated in T-391 and T-392. The report shall be filed and maintained in accordance with the referencing Code Section.

T-394 DATA STORAGE

Data archives shall be in a format appropriate for future access and review. As a minimum, the original reconstructed data images, as well as the original imaging parameters, shall be stored.

(25)

MANDATORY APPENDIX I PROCEDURE QUALIFICATION REQUIREMENTS FOR FLAW SIZING AND CATEGORIZATION

I-310 SCOPE

This Mandatory Appendix provides requirements for the qualification[5] 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.

I-320 GENERAL

The requirements of Article 3 apply except as modified by this Appendix.

I-330 EQUIPMENT

I-335 DEMONSTRATION BLOCKS

I-335.1 General. The following Article 3 paragraphs apply to demonstration blocks: T-334.1.2, T-334.1.3, T-334.1.4, T-334.1.5, and T-334.1.6.

I-335.2 Preparation. A demonstration block shall be prepared by welding or, provided the acoustic properties are similar, the hot isostatic process (HIP) may be used.

I-335.3 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.

I-335.4 Weld Joint Configuration. The demonstration block's weld joint geometry shall be representative of the production joint's details.

I-335.5 Flaw Location.

(a) 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:

(1) one surface flaw on the side of the block representing the component O.D. surface

(2) one surface flaw on the side of the block representing the component I.D. surface

(3) one subsurface flaw per T-321.2.1

(b) When the scan plan to be utilized subdivides a weld into multiple examination zones, a minimum of one flaw per zone is required.

I-335.6 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 the applicable B31 Code Section.

I-335.7 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, no cladding or weld overlay present), then only one surface flaw is required.

I-335.8 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.

I-340 MISCELLANEOUS REQUIREMENTS

I-342 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 or User along with a copy of any software necessary to view the data.

I-380 EVALUATION

I-381 SIZE AND CATEGORY

Flaws shall be sized and categorized in accordance with the written procedure being qualified.

I-382 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%

I-383 SUPPLEMENTAL MANUAL TECHNIQUE ACCEPTABLE PERFORMANCE

Demonstration block flaws may be sized and categorized by a supplemental manual technique outlined in the procedure, only if the automated or semiautomated flaw recorded responses meet the requirements of I-382(a) and/or it is used for the detection of transverse reflectors. Acceptable performance, unless specified by the User or referencing Code Section, 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)

I-390 DOCUMENTATION

I-395 DEMONSTRATION BLOCK RECORD

The required information of T-392 and the following information shall be recorded:

(a) 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, and category (surface or subsurface)]

(b) demonstration block specification and grade, P-number, and heat treat

(c) scanning sensitivity and search unit travel speed

(d) scan plan

(e) scanner and adhering and guiding mechanism

(f) qualification scan data

(g) flaw sizing data [same information as flaw data in (a)]

(h) supplemental manual technique sizing data, if applicable [same information as flaw data in (a)]

(i) the final display processing levels

(25)
NONMANDATORY APPENDIX A EXAMINATION OF WELDS USING FULL MATRIX CAPTURE

A-310 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.

A-320 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.

A-321 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.

A-330 EQUIPMENT

A-332 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).

A-340 MISCELLANEOUS

A-341 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 A-341-1.

A-342 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.

A-342.1 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 A-351.1-1 and A-351.1-2.

A-350 TECHNIQUES

A-351 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 A-341-1
An Illustrated Elementary Transmit/Receive Matrix

	Transmitting Elements				
Receiving 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*_*N*−1
N	Ascan_1_*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.

A-351.1 Typical Workflow Process. Figures A-351.1-1 through A-351.1-4 illustrate the typical workflow processes mentioned in A-350 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.

A-351.2 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 mode during acquisition or the FMC data was stored such that the TFM processing software could reconstruct several modes. Instead of only for that mode, it is possible to apply various TFM processes to stored FMC as well.

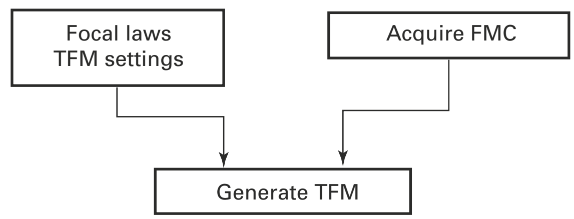
(b) An accurate model of the component can be generated with FMC data, which improves the resolution, and is a function of the array and wedge definition and of the position of the grid. In addition, the ability to resolve component and weld geometry in the reconstructed image has advantages (e.g., verification 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.

Figure A-351.1-1
FMC/TFM Generic Workflow



A-360 CALIBRATION

A-362 GENERAL CALIBRATION REQUIREMENTS

A-362.1 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.

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.

Figure A-351.1-2
Active Focusing Workflow

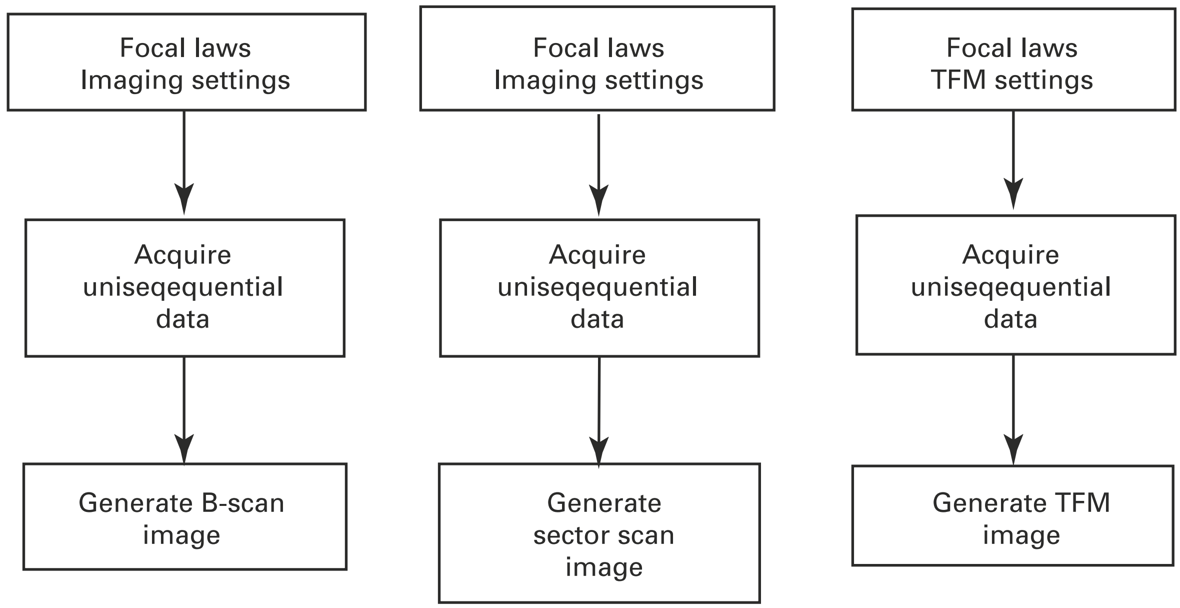


Figure A-351.1-3
Active Focusing Workflow With FMC Data Acquisition

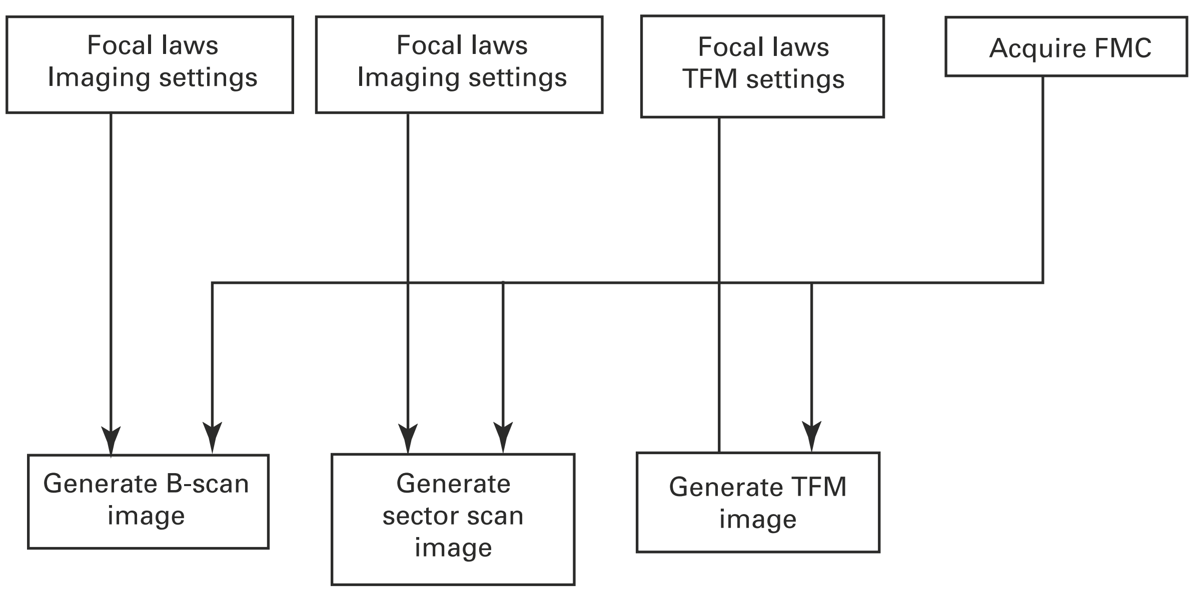
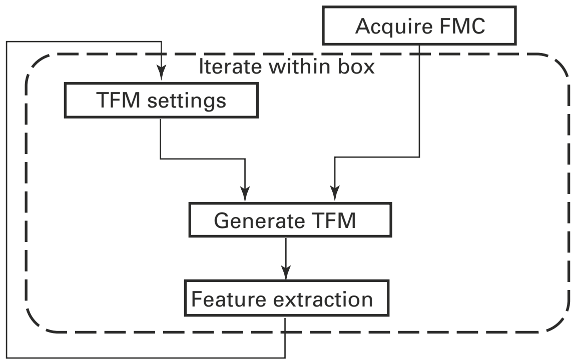


Figure A-351.1-4
Example of an Iterative FMC/TFM Workflow as an Adaptation of That Shown in Figure A-351.1-1



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).

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.

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 3, T-362. 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 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.

A-370 EXAMINATION

A-371 ULTRASONIC 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.

Table A-371-1 and Figure A-371-1 provide examples of different possible modes, but the 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 modes include “direct modes” L–L, L–T, T–L, and T–T and “corner modes” 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 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 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 multimode is then possible within only one FMC acquisition, either in post-processing or in real time if the equipment offers this feature.

A-372 SELECTION OF THE MODES

Since FMC can be considered common to all modes, selection of the modes 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 than other flaw orientations.

A-373 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.

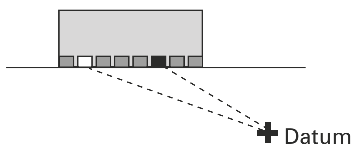
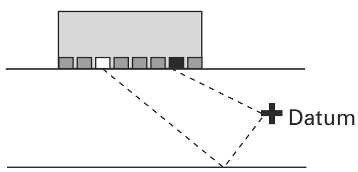
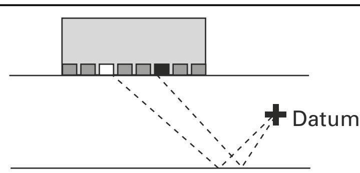
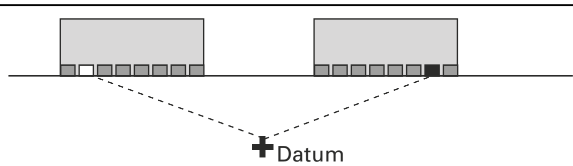
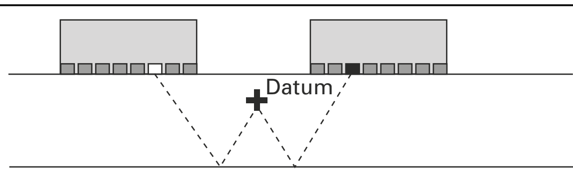
The same FMC provides access to images corresponding to different possible UT modes (e.g., tip diffraction, corner echoes, mode conversions). Since it is possible to calculate all modes from the same FMC data, when the acquisition is properly done and the features are included in the instrument, it is possible to merge different modes, thus creating a reconstruction of the component and what is in it.

A-380 EVALUATION

A-381 DETECTION

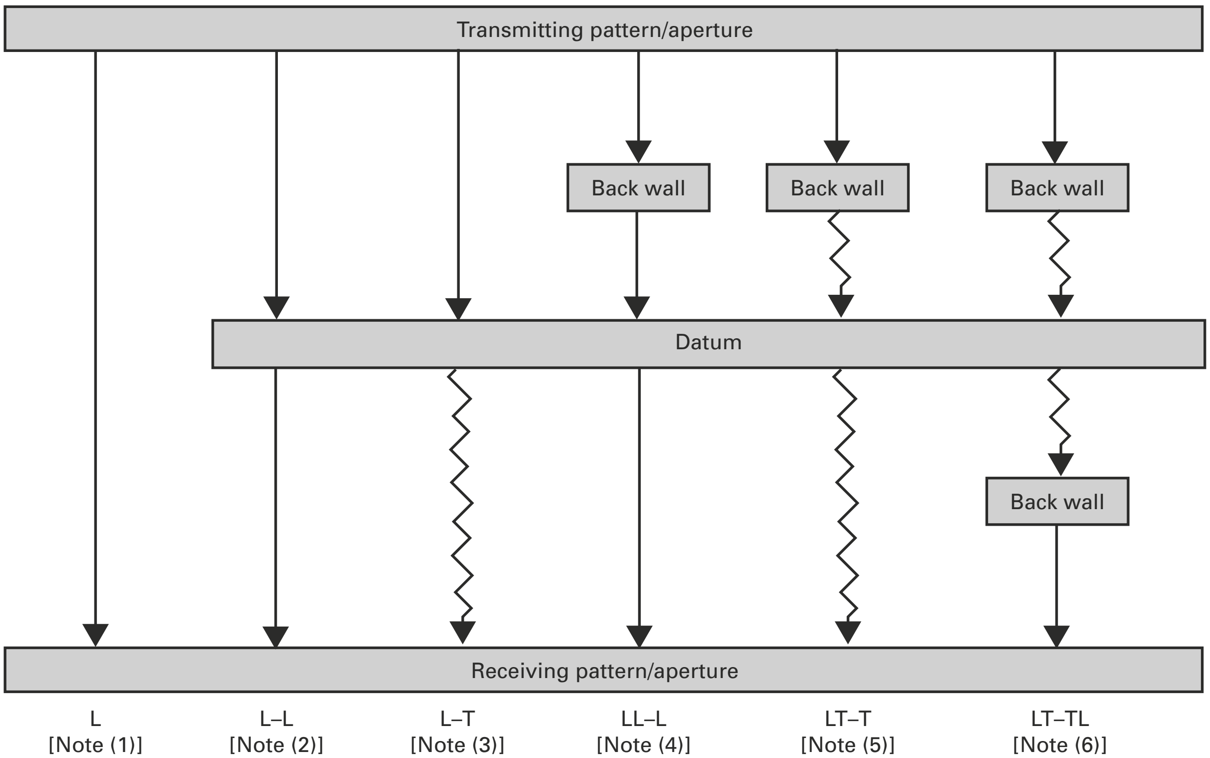
TFM does not necessarily improve resolution or sensitivity, which is more dependent on the array, wedge definition, and particular method used. The potential for better resolution improves when the search unit(s) are properly designed for the examination. Also, the absolute detection capability of the FMC/TFM method can be improved when a combination of 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.

Table A-371-1
Ultrasonic Imaging Modes

Illustrated Example of an Imaging Mode [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 mode.
(2) This is not an exhaustive list of modes.

Figure A-371-1
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 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 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.

ARTICLE 4
ULTRASONIC EXAMINATION METHODS FOR WELDS

T-410 SCOPE

When this Article is specified by a referencing Code Section, the ultrasonic method described in this Article shall be used together with Article 1, General Requirements. Terms used in this Article are defined in I-121.2, UT – Ultrasonics.

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

T-420 GENERAL

For specific applications or techniques, refer to the following:

(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) Article 3 for full matrix capture (FMC) techniques

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 (25)

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 required to aid ultrasonic coupling per T-432.2. If a contoured wedge is used, the calibration block diameter shall also meet the requirements for the selected wedge curvature range in T-432.2(b)(1) or T-432.2(b)(2).

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

T-432.2 Contact Wedges. When required by (a) below, examinations performed on a curved component shall be performed using a contoured wedge, to ensure sufficient ultrasonic coupling is achieved and to limit any potential rocking of the wedge as it is moved along the circumference of the component.

(a) Wedges shall be contoured if the component diameter to be examined is equal to or less than D using the calculation below.

$$D \le \frac{A^2}{0.113\text{ in. }(2.87\text{ mm})}$$

where

A = length of the wedge footprint during circumferential scanning or the width when scanning in the axial direction, in. (mm)

D = the component diameter at the examination surface (I.D./O.D.), in. (mm)

The footprint is defined as the physical dimension of the wedge in the curved direction of the component.

(b) When contouring is required per (a) above, the wedge contour dimension shall be selected from the tables in (1) or (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 the O.D.

Actual Component Outside Diameter, in. (mm)	Allowable Increase in Contour Diameter Over Component O.D., in. (mm)
<4 (<100)	−0 to +1 (+25)
≥4 to <10 (≥100 to <250)	−0 to +2 (+50)
≥10 to <18 ((≥250 to <455)	−0 to +4 (+100)
≥18 to <23 (≥455 to <580)	−0 to +6 (+150)
≥23 (>580)	−0 to +10 (+250)

(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 (<100)	+0 to −1 (−25)
≥4 to <10 (≥100 to <250)	+0 to −2 (−50)
≥10 to <18 (≥250 to <455)	+0 to −4 (−100)
≥18 to <23 (≥455 to <580)	+0 to −6 (−150)
≥23 (>580)	+0 to −10 (−250)

T-432.3 Weld Metal Overlay Cladding — Search Unit.[6] 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. Nonmandatory Appendices S and U (as applicable) may be 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 of the following:

(1) the corresponding reference reflector (same type and dimensions) in the basic calibration block and in the component to be examined

(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. (25)

(a) Calibration 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, including integral clad, 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) Calibration Block Cladding. When the component material is clad, the calibration block shall be clad and shall meet the following:

(1) Clad Thickness. The thickness of the cladding on the calibration block shall be at least as thick as the cladding on the part to be examined.

(2) Clad Deposition. If the cladding deposition of the component to be examined is known, deposition of clad on the calibration block shall be by the same method. When the cladding method is unknown or the method of cladding used on the component is impractical for calibration block cladding, deposition of clad may be by the manual method.

(3) Clad Material. When the clad on opposite sides of a weld are the same P-, A-, or F-numbers, the calibration block shall be clad with the same P-, A-, or F-numbers. When the clad on opposite sides of a weld are unlike P-, A-, or F-numbers, the calibration block shall be clad with the same P-, A-, or F-numbers 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 material types.

When the weld is clad with a different material or different deposition methods other than the adjoining parent materials, 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). (25) For examinations 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 examinations on surfaces in the range of curvature from 0.9 times to 1.5 times the basic calibration block diameter. 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.

Figure T-434.1.7.2
Ratio Limits for Curved Surfaces

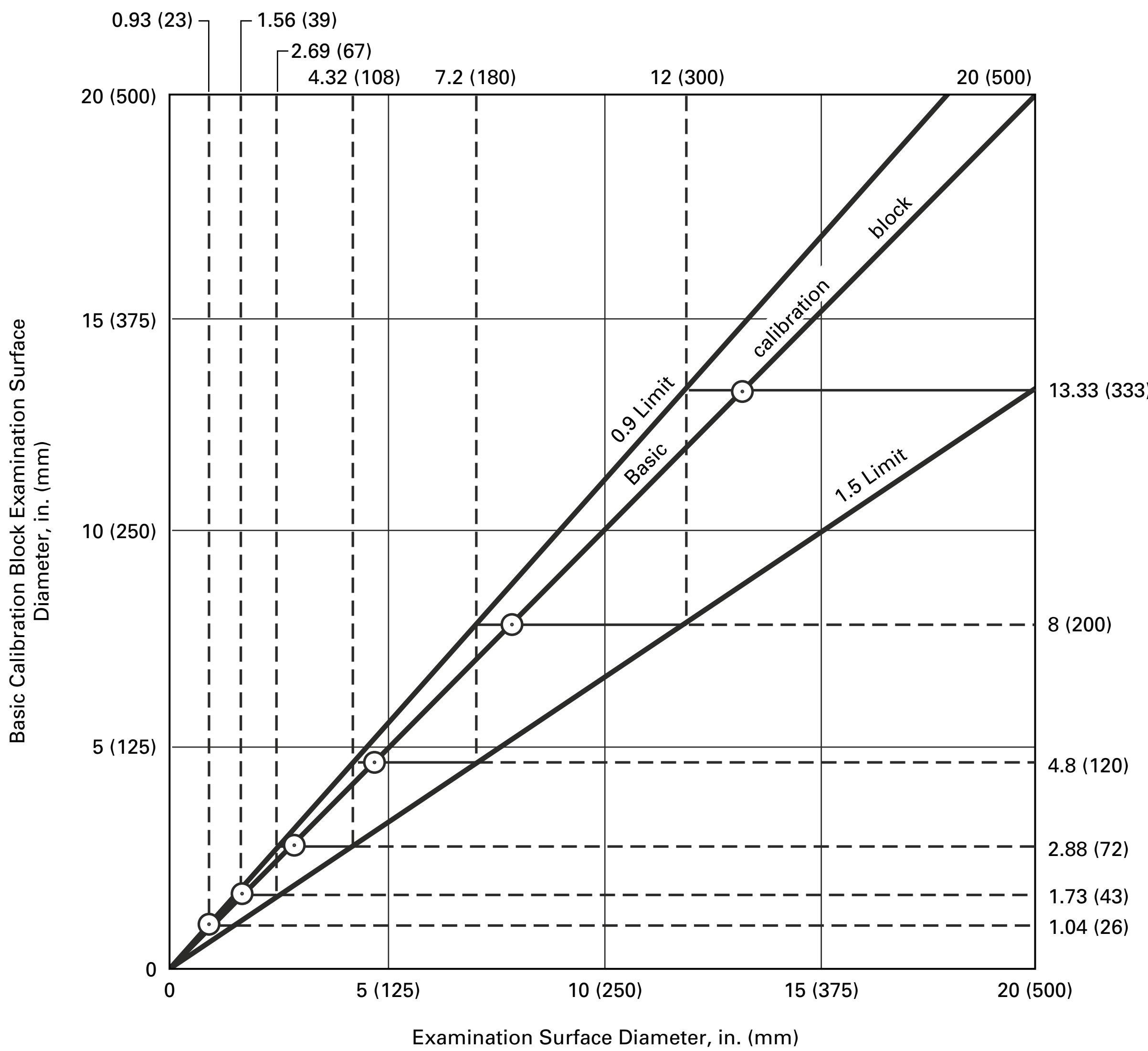
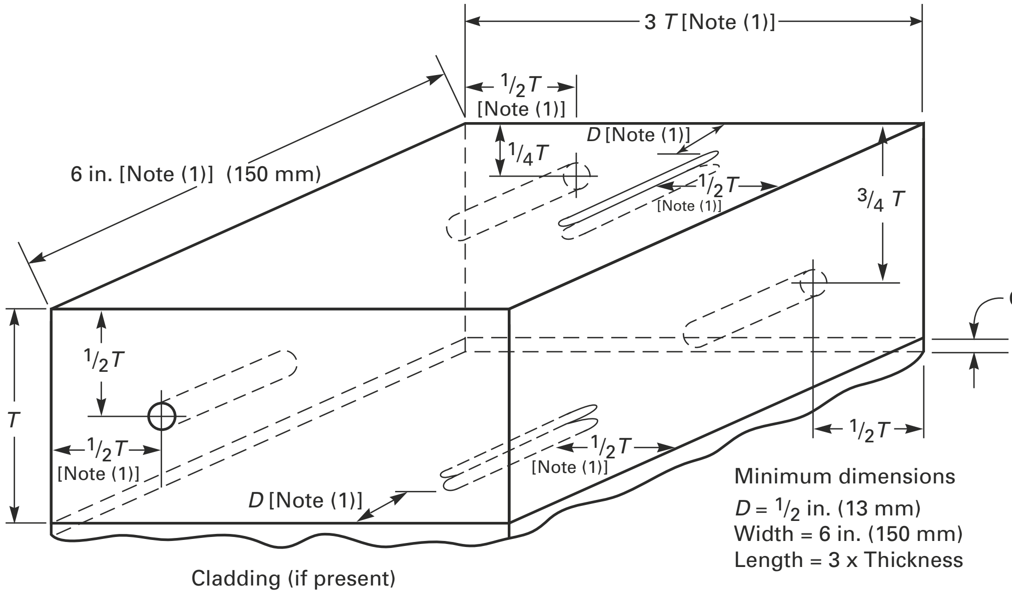


Figure T-434.2.1
Nonpiping Calibration Blocks



Notch Dimensions, in. (mm)
Notch depth = 1.6% T to 2.2% T
Notch width = $^1/_4$ (6) max.
Notch length = 1 (25) min.

Weld Thickness (t), in. (mm)	Calibration Block Thickness (T), in. (mm)	Hole Diameter, in. (mm)
≤1 (≤25)	$^3/_4$ (19) or t	$^3/_{32}$ (2.5)
>1 (>25) through 2 (50)	$1^1/_2$ (38) or t	$^1/_8$ (3)
>2 (>50) through 4 (100)	3 (75) or t	$^3/_{16}$ (5)
>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 ±$^1/_{32}$ in. (0.8 mm). The tolerance for hole location through the calibration block thickness (i.e., distance from the examination surface) shall be ±$^1/_8$ in. (3 mm).
(d) For blocks less than $^3/_4$ in. (19 mm) in thickness, only the $^1/_2T$ 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 $^1/_4T$, $^1/_2T$, and $^3/_4T$ 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 $^1/_4$ 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 $^1/_{16}$ in. (1.5 mm).

T-434.2.3 Block Curvature. The block curvature shall be in accordance with T-434.1.7.

T-434.2.4 Alternate Block. Alternatively, the block may be constructed as shown in Nonmandatory Appendix J, Figure J-431.

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.[7] (23)

T-434.4.1 Calibration Blocks for Technique One.

(a) 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.

(b) 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.

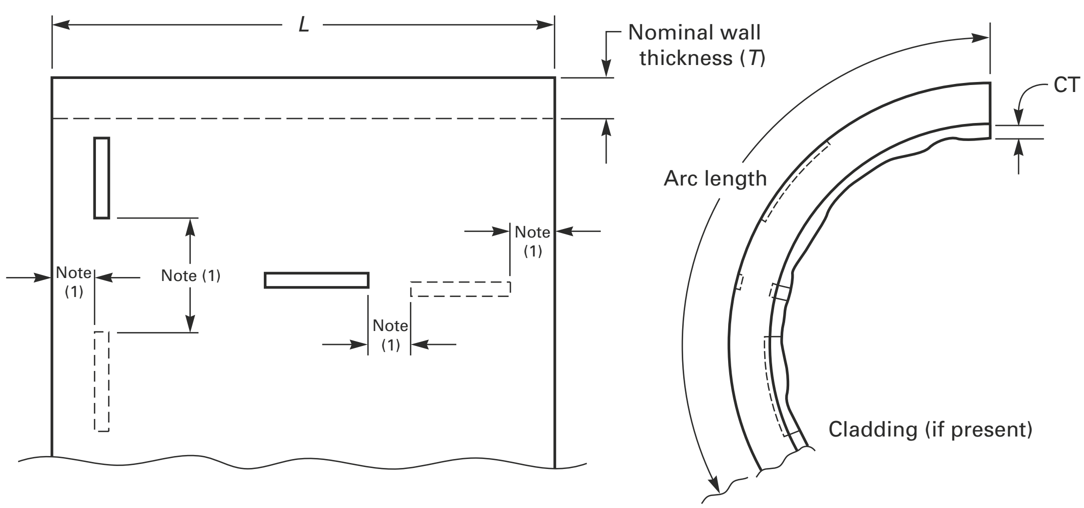
(c) The block curvature shall be in accordance with T-434.1.7.

T-434.4.2 Alternate Calibration Blocks for Technique One.

(a) Alternately, calibration blocks as shown in Figure T-434.4.2.1 or Figure T-434.4.2.2 may be used.

(b) 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.

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 $8T$, 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 $3T$, 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.

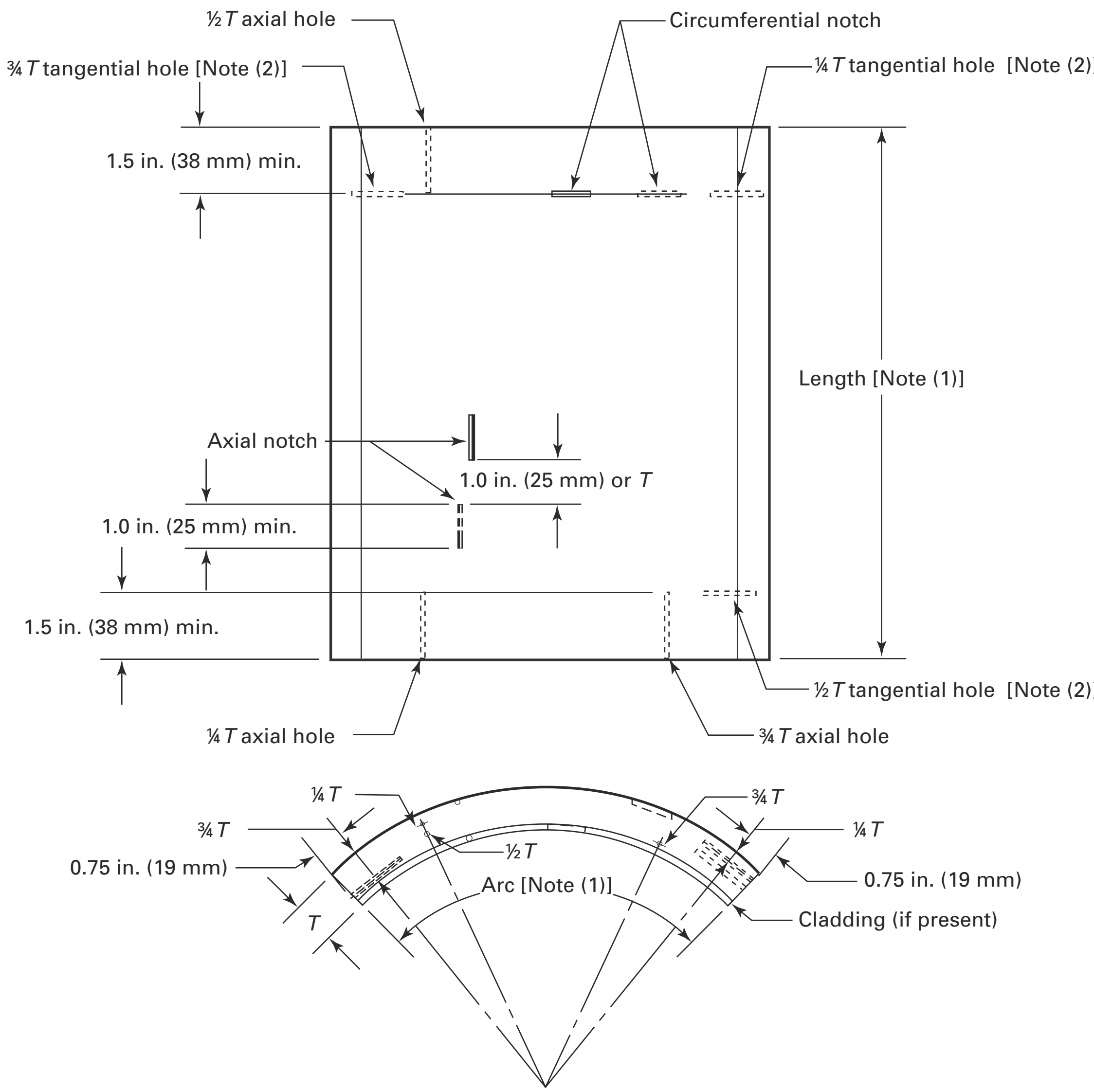
(f) Two blocks shall be used when a weld joining two different thicknesses of material is examined and a single block does not satisfy the requirements of T-434.3.

(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.

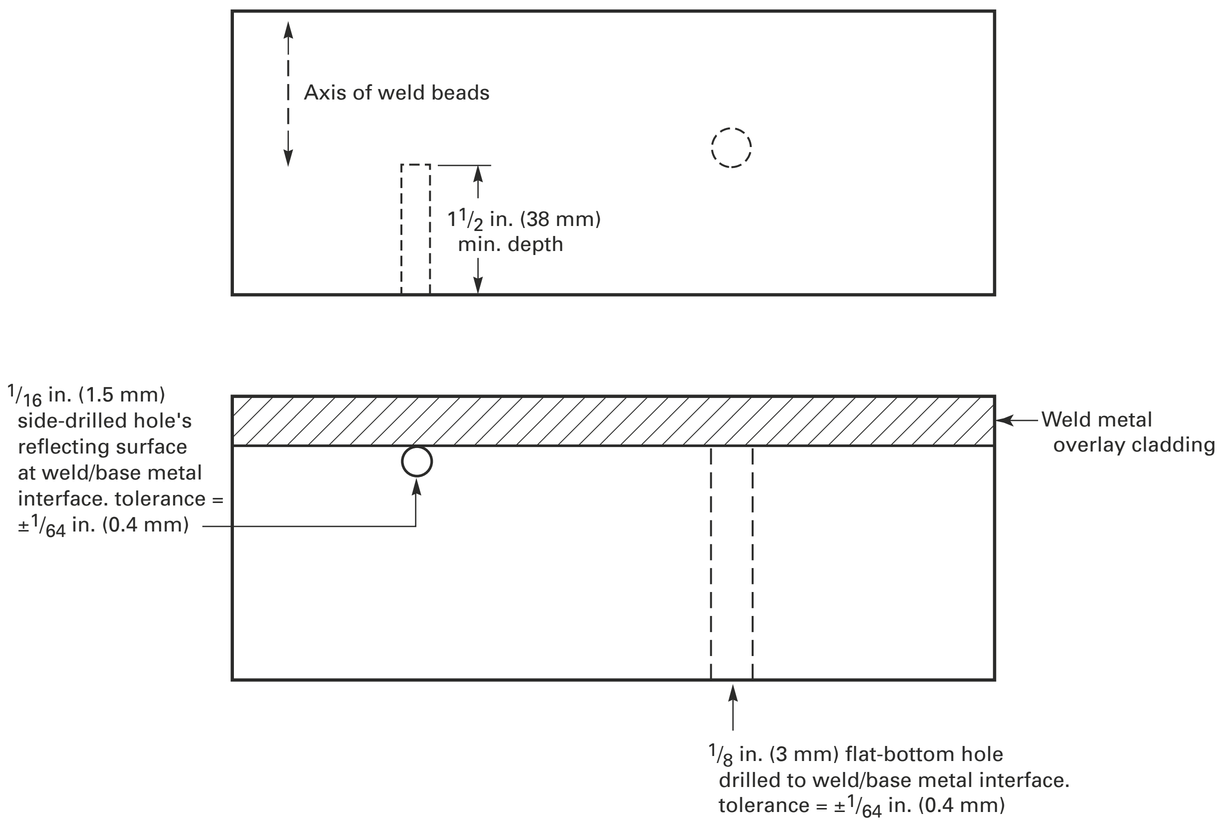
Figure T-434.3-2
Alternate Calibration Block for Piping



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



(c) The block curvature shall be in accordance with T-434.1.7.

T-434.4.3 Calibration Block for Technique Two.

(a) 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.

(b) 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 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.

(c) The block curvature shall be in accordance with T-434.1.7.

T-434.5 Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal Calibration Blocks.

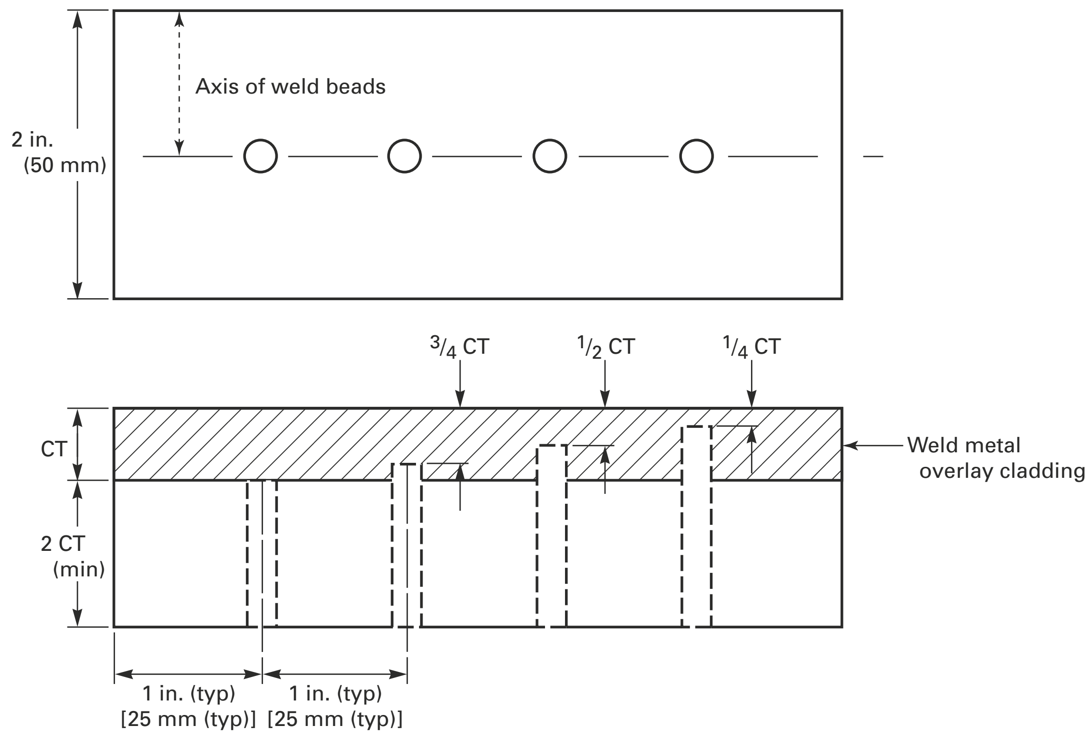
T-434.5.1 Calibration Block.

(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.

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).

(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.

T-440 MISCELLANEOUS REQUIREMENTS

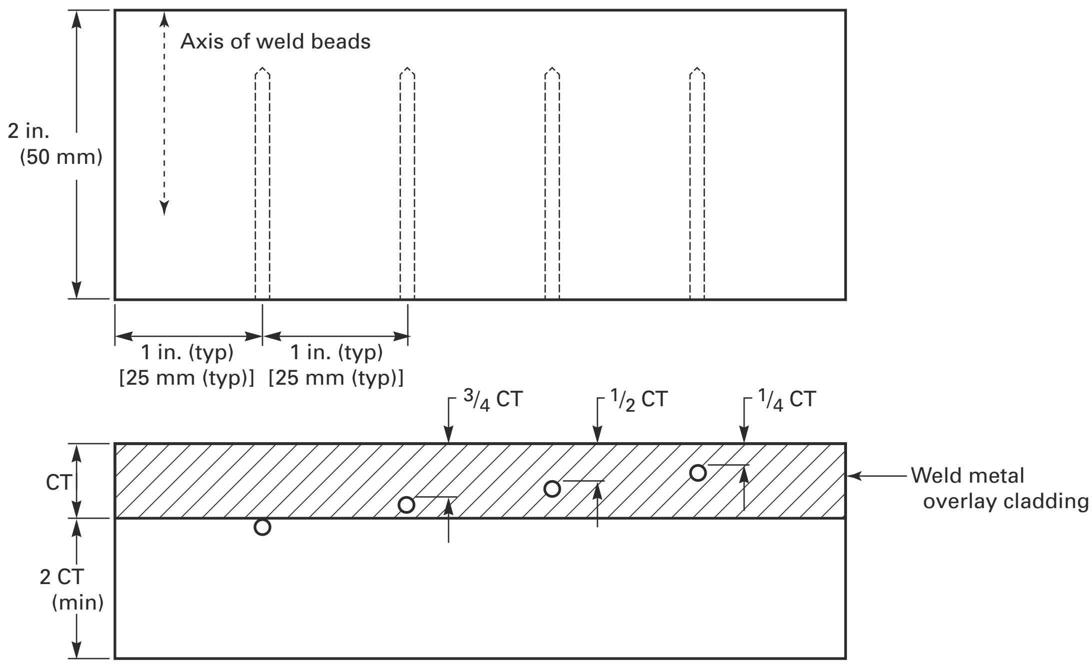
T-441 IDENTIFICATION OF WELD EXAMINATION AREAS

(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.

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 ±$^1/_{64}$ 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

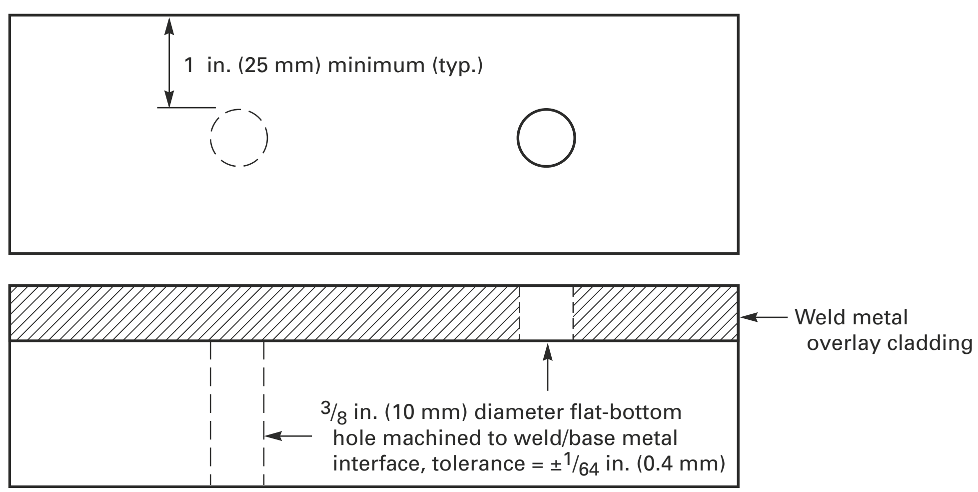
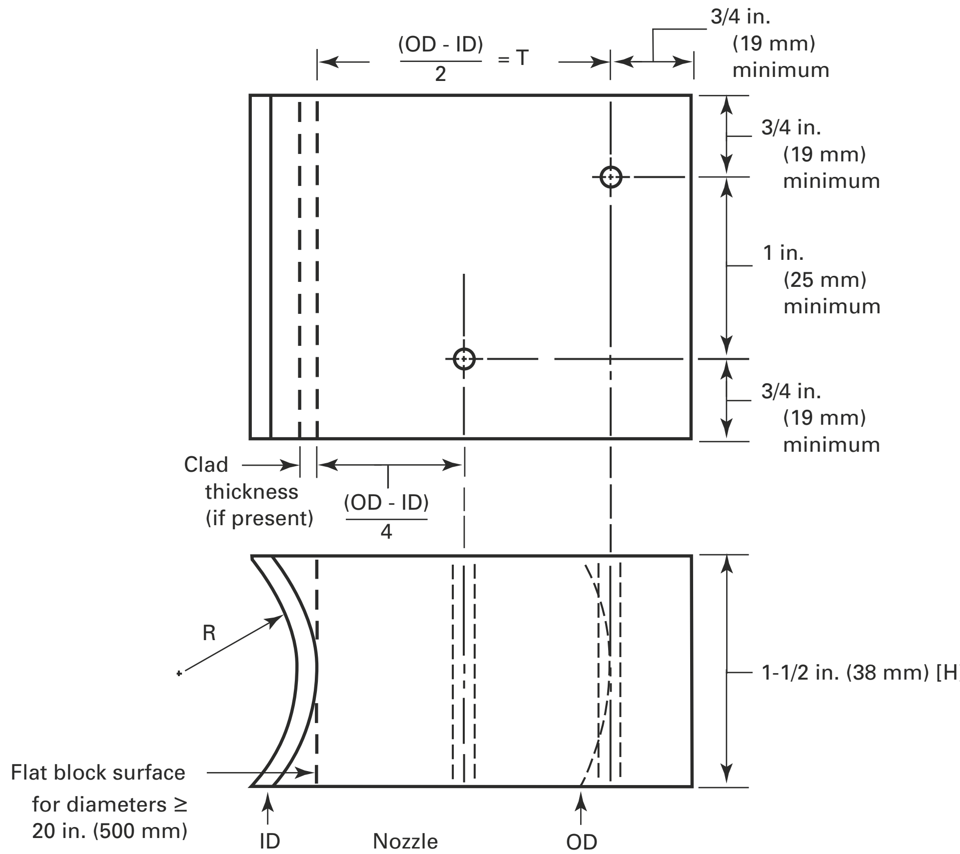


Figure T-434.5.1
Calibration Block for Straight Beam Examination of Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal



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

(25) 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(b).

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. For the purposes of this paragraph, *high alloy steel* is defined as all stainless steels and any other alloy steel in which the sum of all elements, other than iron, exceeds 10% of its weight. 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(b) 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 search units producing refracted longitudinal waves.

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.

(25) **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 side-drilled holes. 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[8] 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 H 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

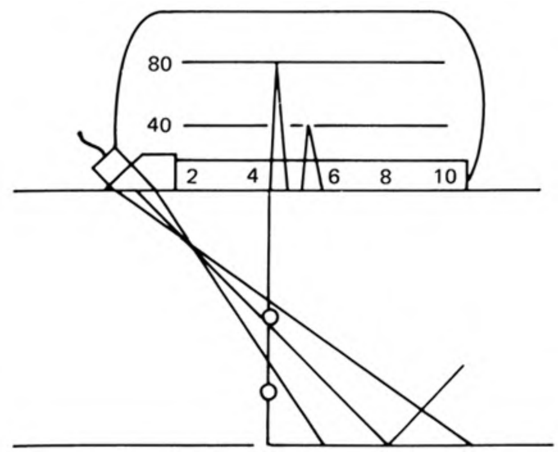
I-410 SCOPE

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 $\frac{1}{2}T$ 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	32% to 48%
80%	−12 dB	16% to 24%
40%	+6 dB	64% to 96%
20%	+12 dB	64% to 96%

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.

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.

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-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 within the lesser of $^3/_4$ in. (19 mm) or 25% of the nominal thickness of the piece to be examined. Reference reflector size is based on the thickness to be examined, and an adequate number of holes shall exist to comply with III-434.2.1 requirements.

III-434.2.3 Alternate Block. The requirements of T-434.2.4 are not applicable to the TOFD technique.

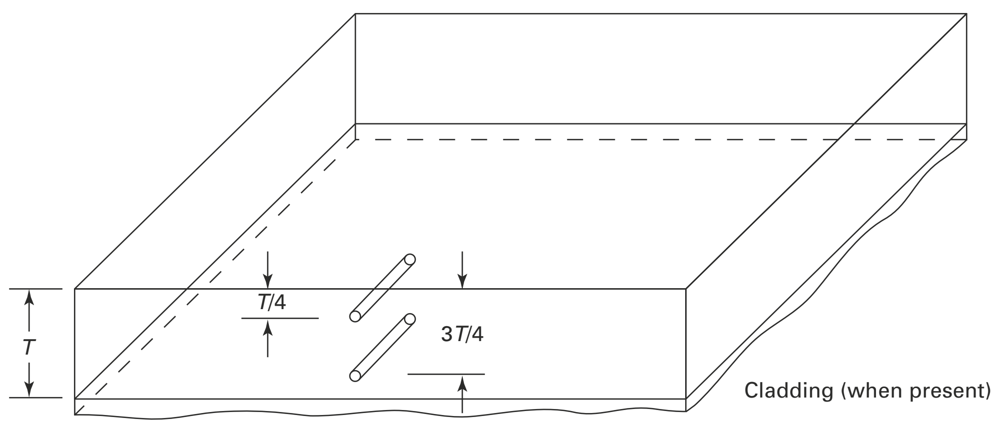
III-434.3 Piping Calibration Block. The requirements of T-434.3 are not applicable to the TOFD technique.

III-434.4 Cladding Calibration Blocks. The requirements of T-434.4 are not applicable to the TOFD technique.

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

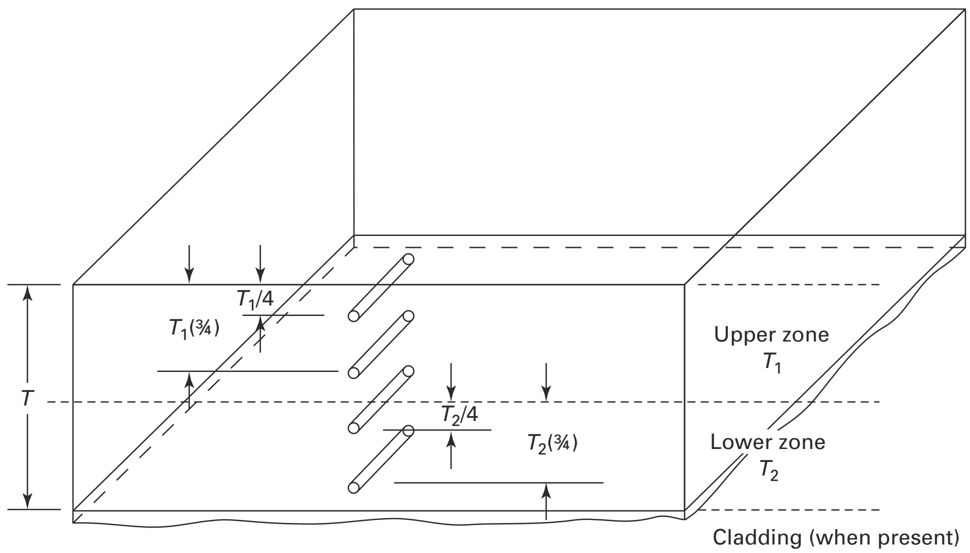
Figure III-434.2.1(a)
TOFD Reference Block



Weld Thickness, in. (mm)	Hole Diameter, in. (mm)
≤1 (≤25)	$^3/_{32}$ (2.5)
>1 (>25) through 2 (50)	$^1/_8$ (3)
>2 (>50) through 4 (100)	$^3/_{16}$ (5)
>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 ±$^1/_{32}$ in. (±0.8 mm). The tolerance on location through the block thickness shall be ±$^1/_8$ 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

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.

(a) For single-zone examination or for the uppermost zone of a multiple-zone examination, set the TOFD probes on the surface to be used for calibration and set the gain control so that the lateral wave amplitude is between 40% and 90% of the full screen height (FSH) and the baseline noise level is between 5% and 10% FSH. This is the reference sensitivity setting.

(b) For additional zones below the uppermost zone in multiple-zone examinations, set the baseline noise level between 5% and 10% FSH. This is the reference sensitivity setting.

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 examination area [as defined in the referencing Code Section and meeting the requirements of Figure III-434.2.1(a) or Figure III-434.2.1(b), as applicable]. 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.

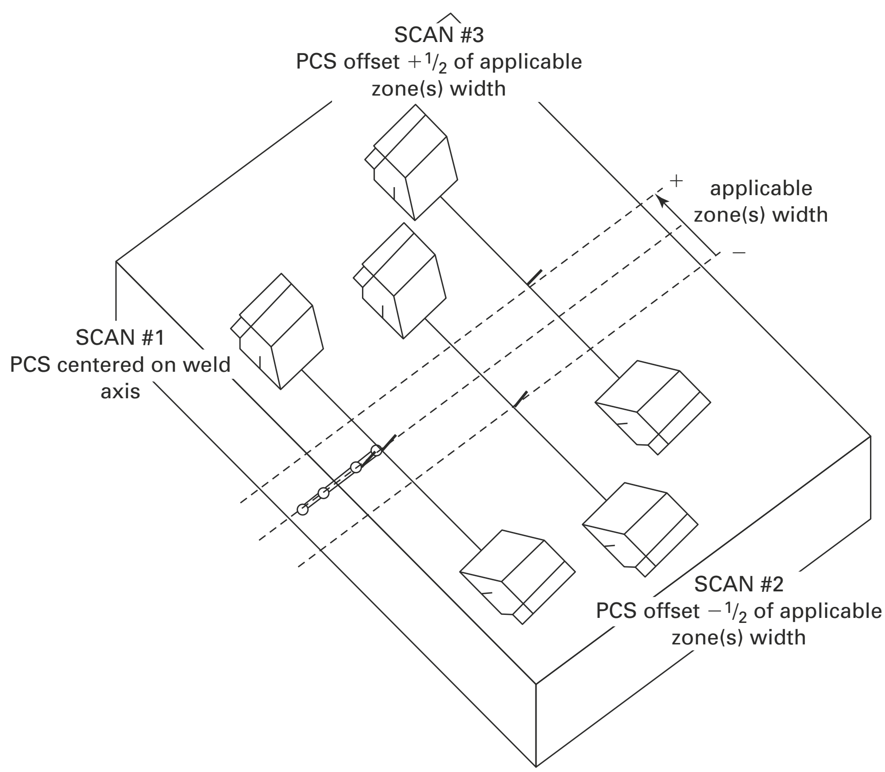
III-464 CALIBRATION FOR PIPING

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 actual 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 signal to the mode-converted back-wall signal shall also be included in the data collected when required by the referencing Code Section. (25)

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 using a technique other than TOFD. This examination may be performed using manual, semiautomated, or automated ultrasonic examination techniques; if semiautomated or automated, 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 back wall 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.

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.

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

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

Table IV-421
Requirements of a Manual Linear Phased Array Raster Scanning Examination Procedure

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.

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.

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 stand-off 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.

(25)

Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures

Requirements (as Applicable)	Workmanship Essential	Workmanship Nonessential	Fracture Mechanics Essential	Fracture Mechanics 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 Essential	Workmanship Nonessential	Fracture Mechanics Essential	Fracture Mechanics 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

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.

VII-421 WRITTEN PROCEDURE REQUIREMENTS

VII-421.1 Requirements. Procedures shall be as detailed for the applicable ultrasonic technique.

VII-421.2 Procedure Qualification. When required by the referencing Code Section, in lieu of the requirements in T-150(d), the procedure shall be considered qualified when the supervising Level III and the Inspector are satisfied that the indications produced by the demonstrated procedure reveal the length, location, orientation, quantity, and characterization of the discontinuities known to be present in the examined test specimen.

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.

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-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 VII-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. VII-467.3 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

(25) VII-467 CALIBRATION CONFIRMATION

VII-467.1 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-467.2 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-467.2.1 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-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 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 back wall removal and SAFT processing, etc.) have been completed.

VII-486 SUPPLEMENTAL MANUAL TECHNIQUES

Flaws detected during the automated or semiautomated 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

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

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.

VIII-421 WRITTEN PROCEDURE REQUIREMENTS

(**25**) **VIII-421.1 Requirements.** Procedure qualification shall comply with Article 1, T-150(d). 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).

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.

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.

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

(25) VIII-467 CALIBRATION CONFIRMATION

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 Non-Distance–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 back wall 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.[9]

(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

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[5] 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%

(25) 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 Section, 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-495 DEMONSTRATION BLOCK RECORD

(a) The required information of T-492 and the following information shall be recorded:

(1) 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, and category (surface or subsurface)]

(2) demonstration block specification and grade, P-number, and heat treat

(3) scanning sensitivity and search unit travel speed

(4) scan plan

(5) scanner and adhering and guiding mechanism

(6) qualification scan data

(7) flaw sizing data [same information as flaw data in I-395(a)]

(8) supplemental manual technique(s) sizing data, if applicable [same information as flaw data in I-395(a)]

(9) the final display processing levels

(b) When TOFD is to be used for qualification, the following shall also be recorded:

(1) probe center spacing (PCS)

(2) data sampling spacing

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

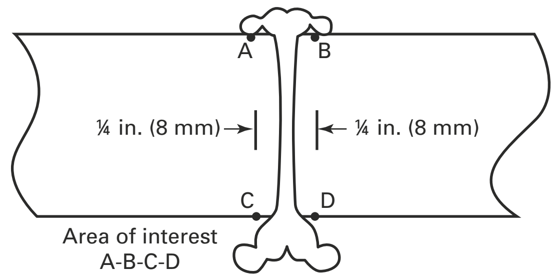
(b) 0.08 in. (2 mm) for material greater than 3 in. (75 mm) thick

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.

Figure X-471.1
Fusion Pipe Joint Examination Volume



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 $^1/_2$ 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,[10] 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 $^1/_4T$ 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.[11] 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.

B-461.1.3 Repeat Adjustments. Repeat delay and range control adjustments until the $^1/_4T$ and $^3/_4T$ 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 $^1/_4T$.

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

Figure B-461.1
Sweep Range (Side-Drilled Holes)

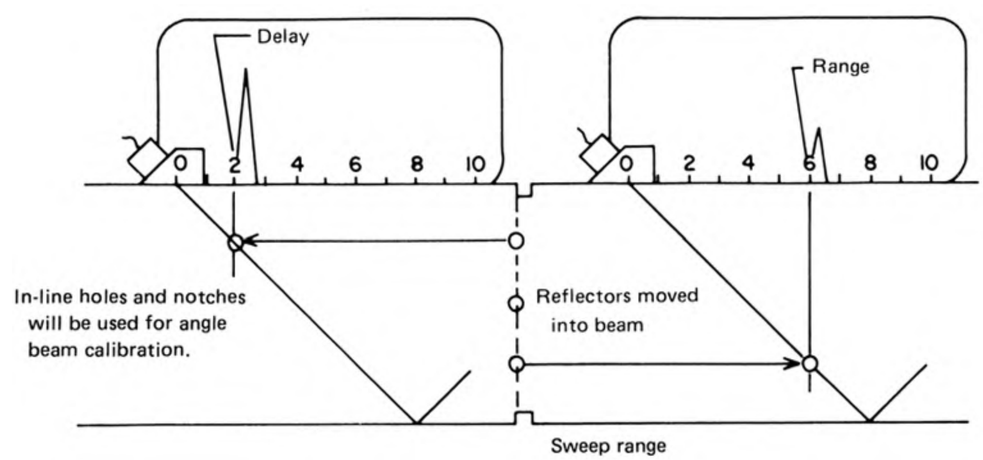
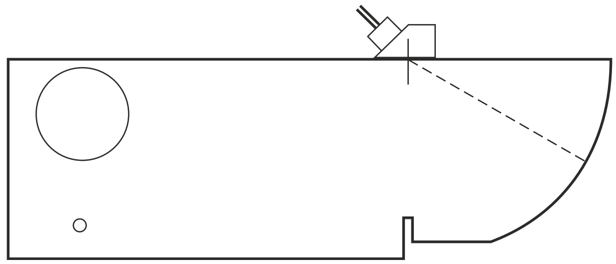


Figure B-461.2
Sweep Range (IIW Block)



point of the radius. Other IIW blocks provide 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.

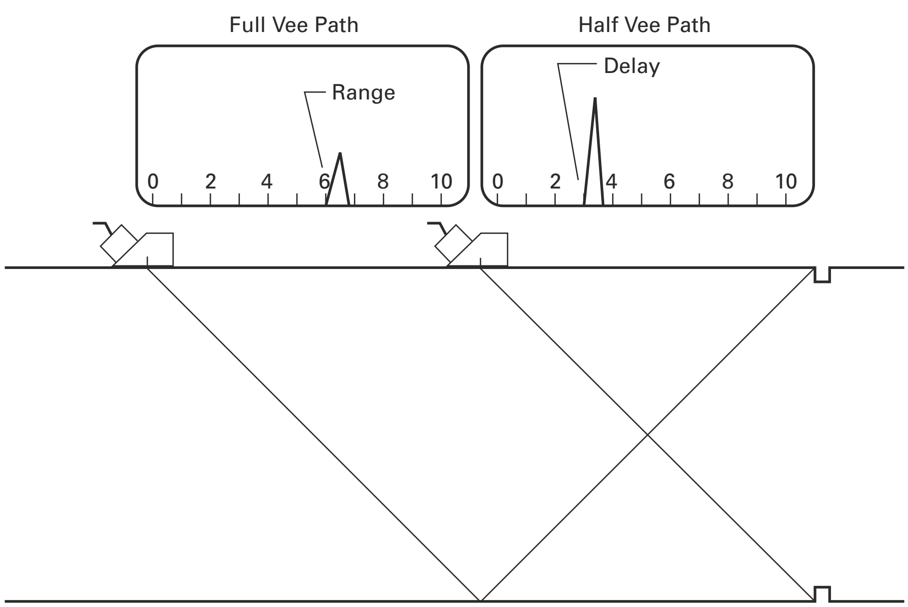
B-461.2.4 Sweep Readings. Two divisions on the sweep now equal $^1/_5$ of the screen range selected.

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 $^3/_4T$ 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 $^3/_4T$ position.

(g) Connect the screen marks for the SDHs to provide the distance–amplitude correction (DAC) curve.

(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 $^3/_4T$ and $^5/_4T$ 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 $^5/_4T$ SDH position, position the search unit for maximum amplitude from the $^3/_4T$ 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 ($^5/_4T$ 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 DAC curve.

(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)

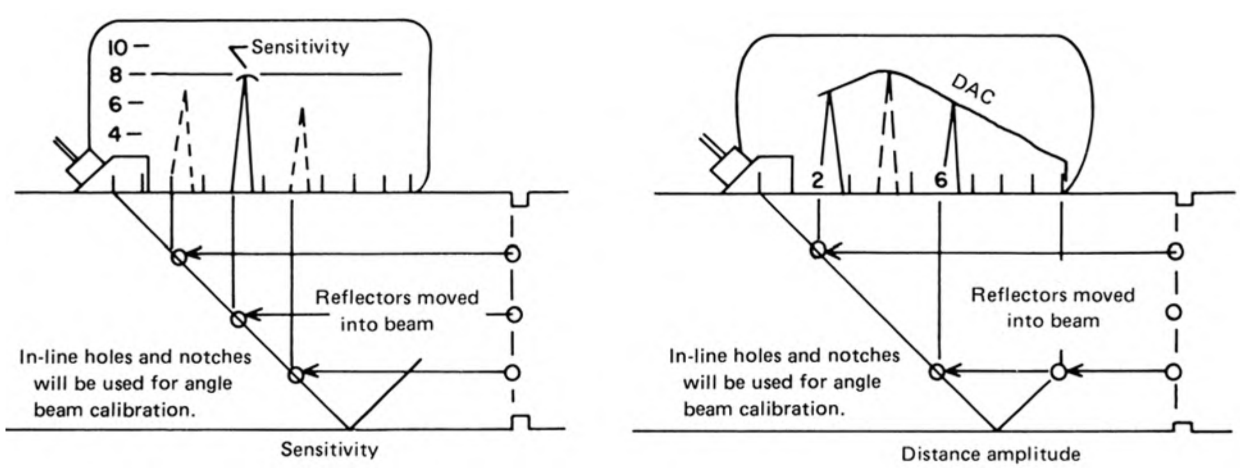
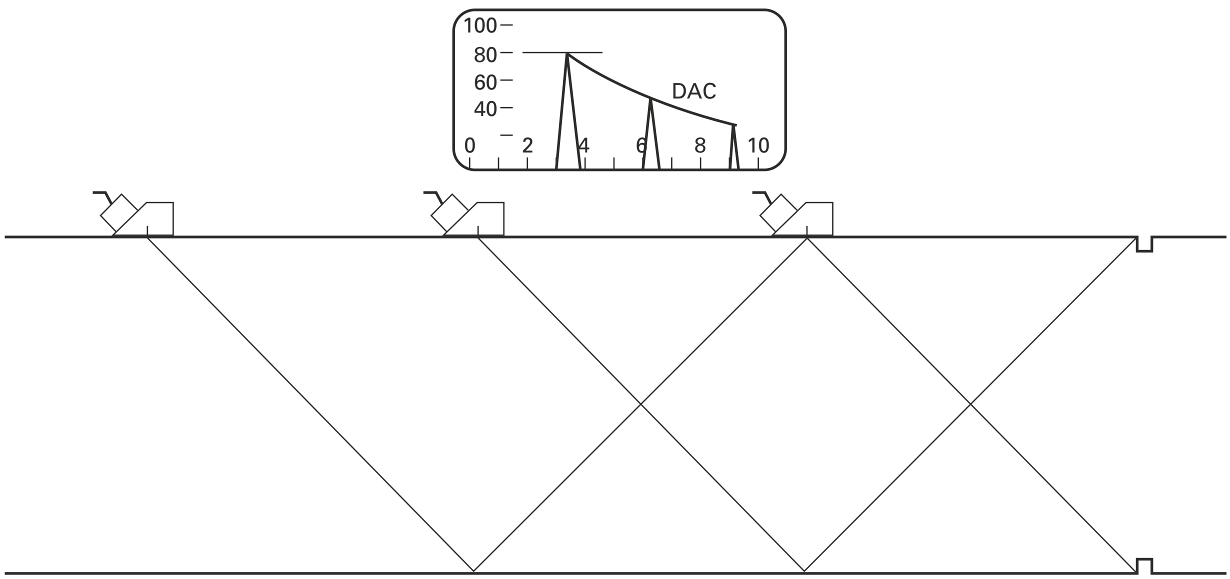


Figure B-462.3
Sensitivity and Distance–Amplitude Correction (Notches)



B-463 DISTANCE–AMPLITUDE CORRECTION INNER ¼ 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.[12]

B-464.1 ¼T 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.)

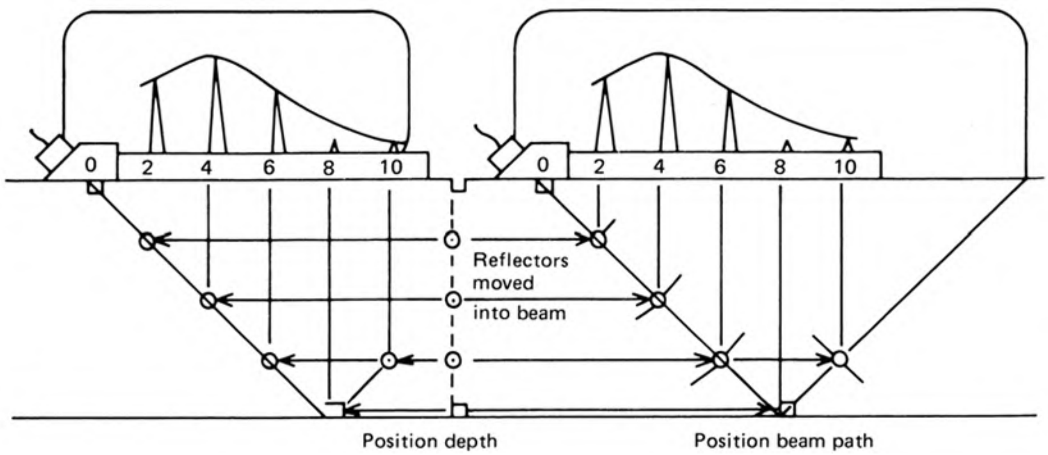
B-464.2 ½T and ¾T SDH Indications. Position the search unit for maximum indications from the $^1/_2T$ and $^3/_4T$ SDHs. Keep the same end of the indexing strip against the front of the search unit. Mark the numbers 4 and 6 on the indexing strip at the scribe line, which are directly above the SDHs.

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

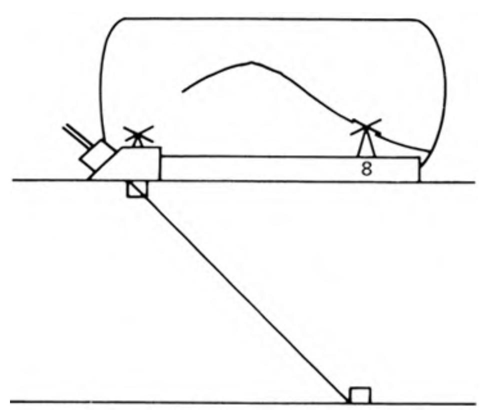
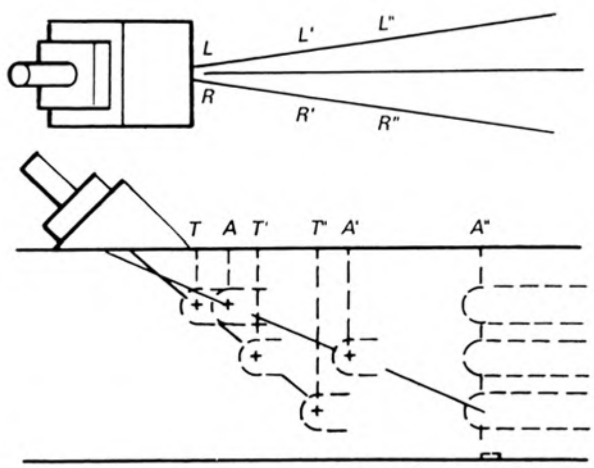


Figure B-466
Beam Spread



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.[13]

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.[13]

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[14] (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

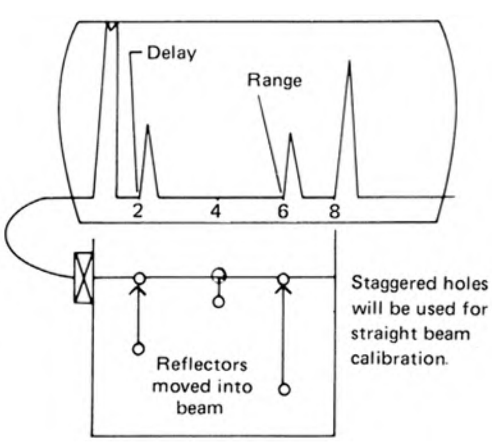
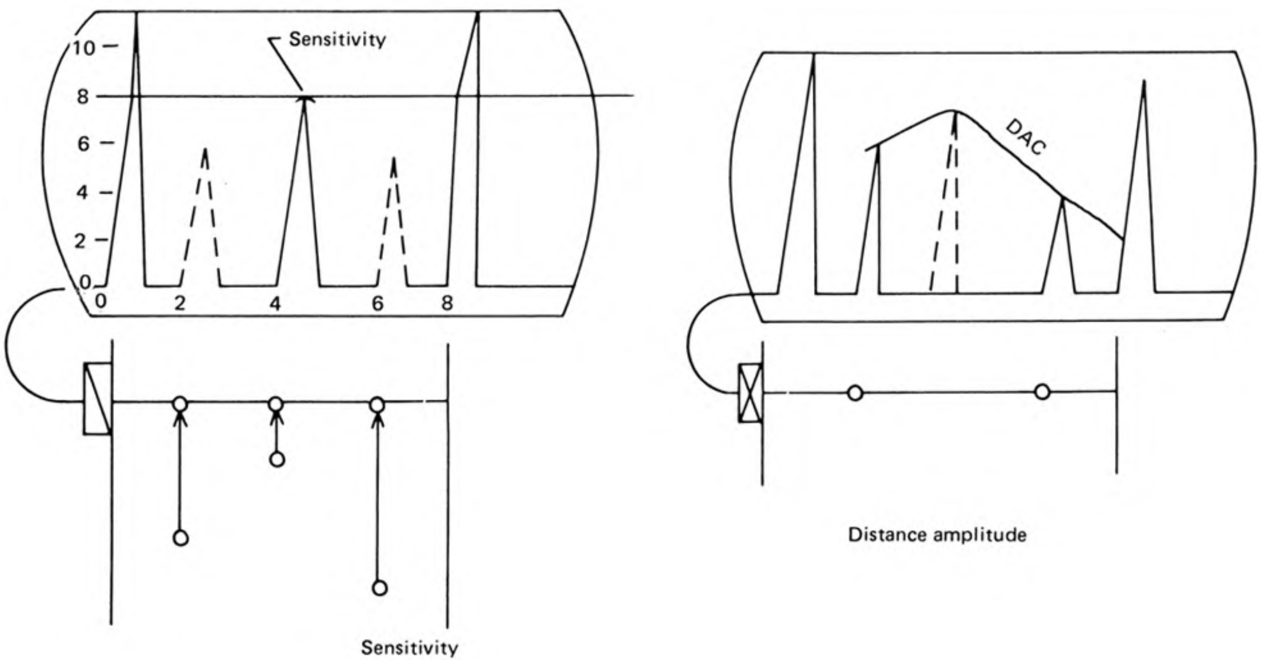


Figure C-462
Sensitivity and Distance–Amplitude Correction



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[15]) 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).

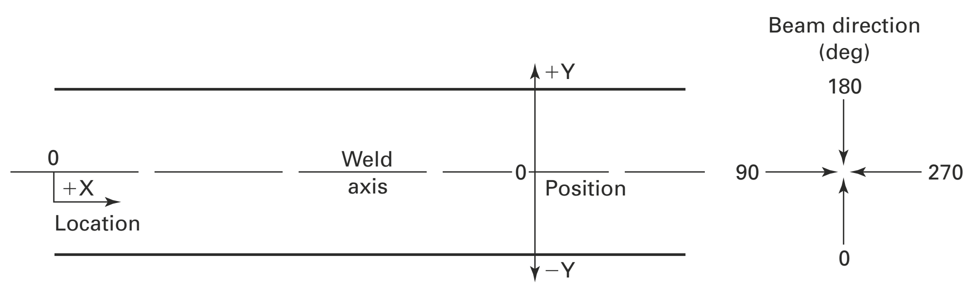
(c) Determine and record the search unit location (X) with respect to the 0 point.

(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.

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.

Figure D-490
Search Unit Location, Position, and Beam Direction



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 beamforming, 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.

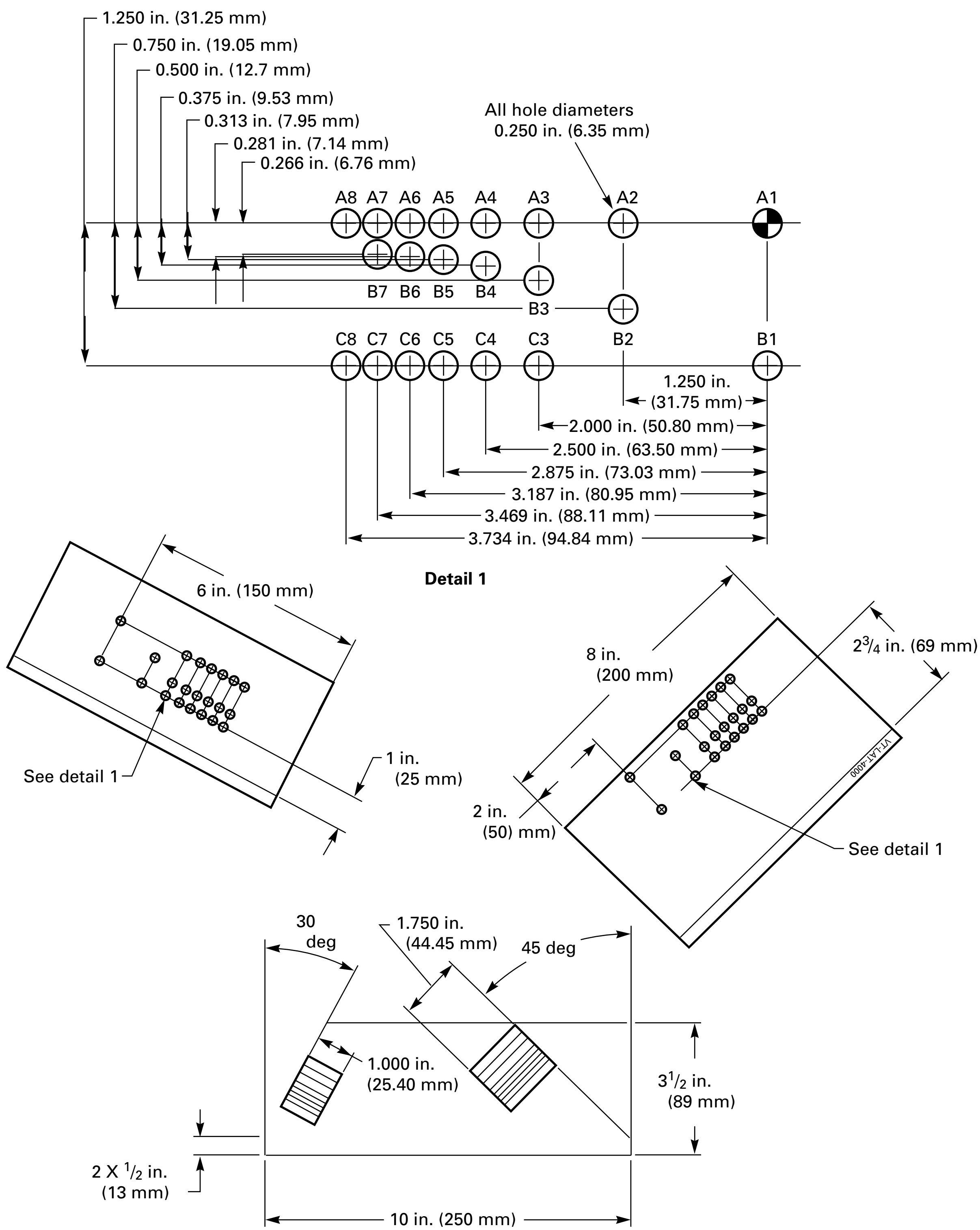
All constraints for SAFT-UT apply to L-SAFT and vice versa. The difference between L-SAFT and SAFT-UT is that SAFT-UT provides a higher resolution image than can be obtained with L-SAFT.

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

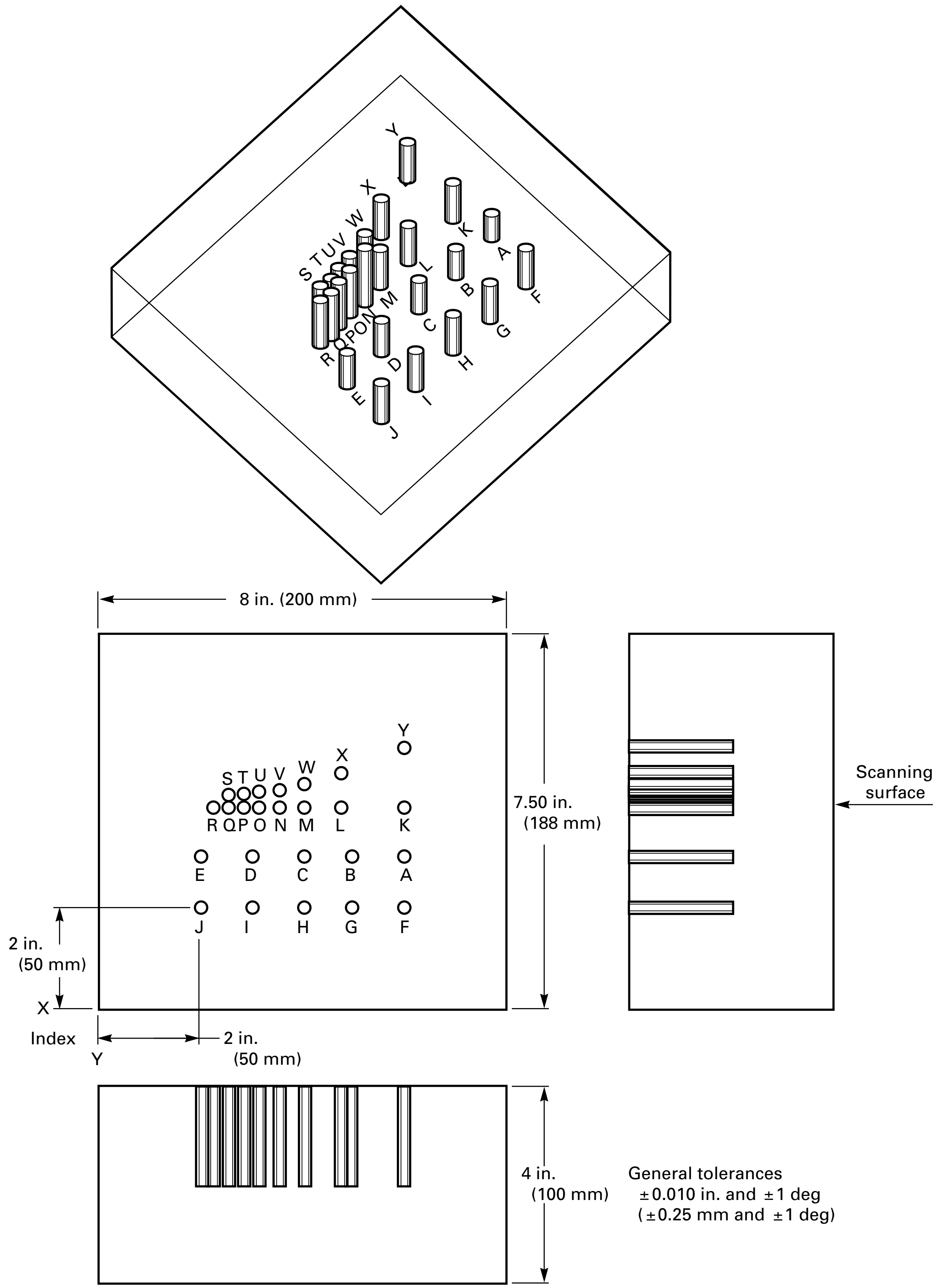
The UT-Phased Array Technique is a process wherein UT data are generated by controlled incremental variation of the ultrasonic beam angle in the azimuthal or lateral direction while scanning the object under examination. This process offers an advantage over processes using conventional search units 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.

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

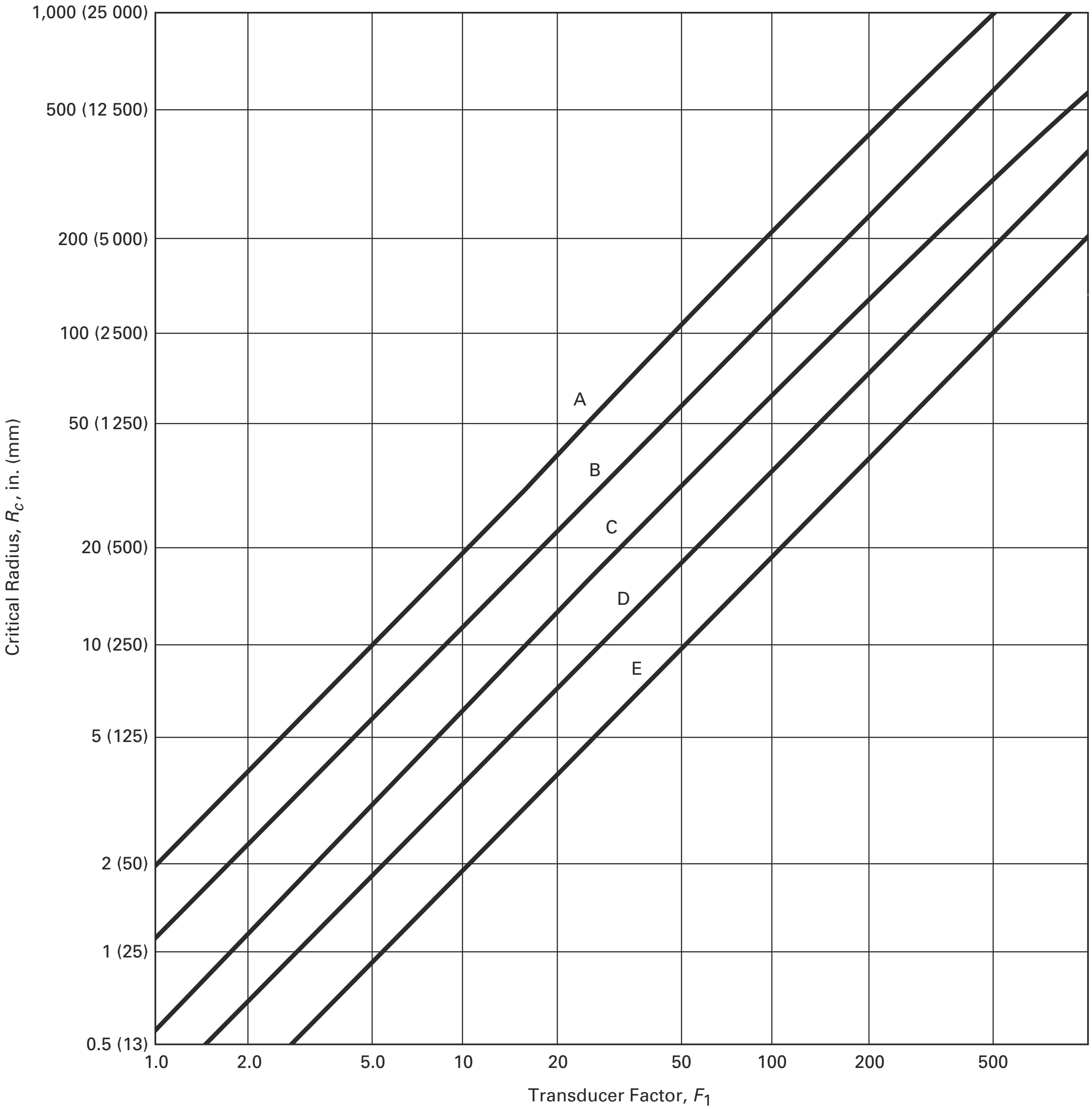
U.S. Customary Units

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

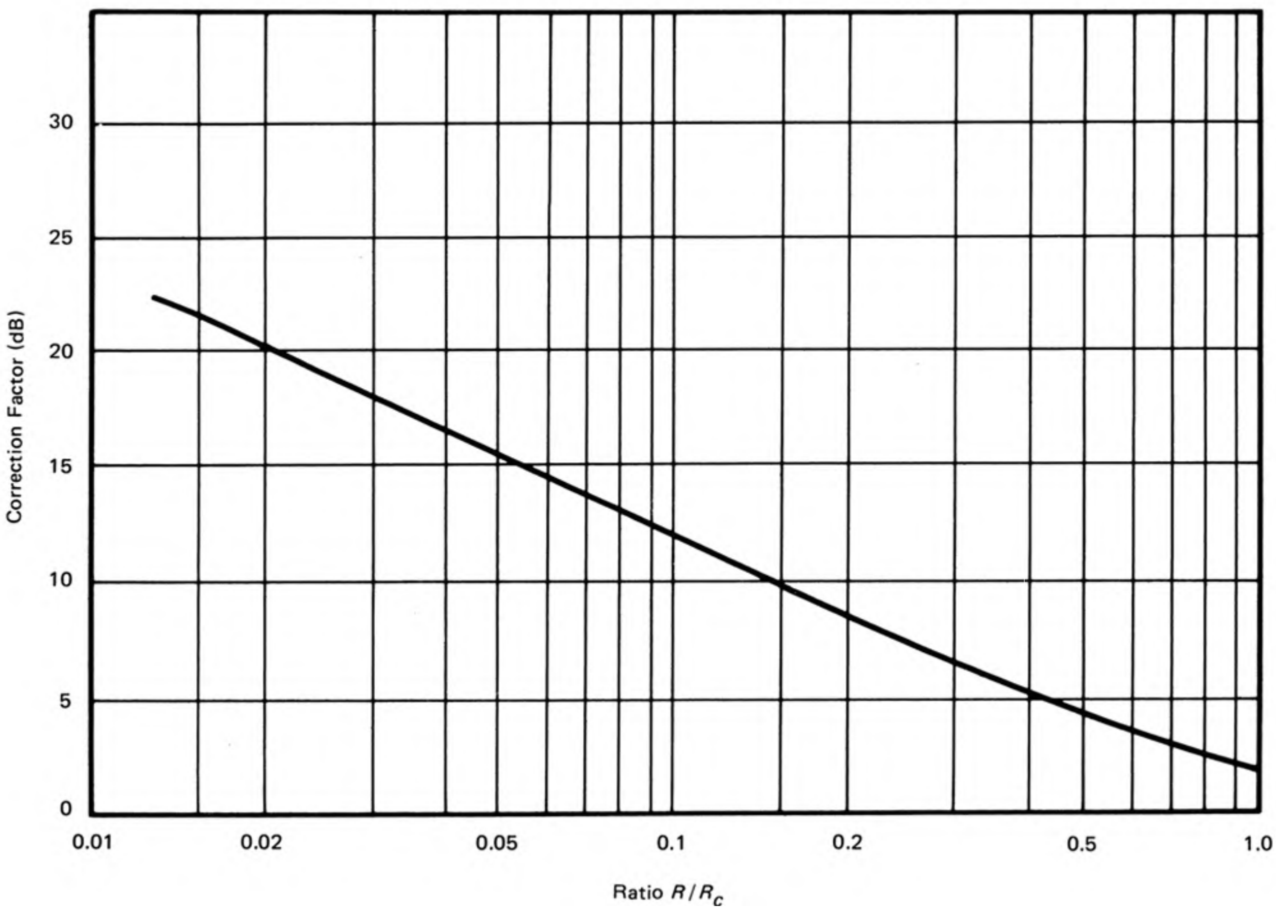
Frequency, MHz	Transducer Diameters, mm				
	6.4	13	19	25	29
	F_1, mm				
1.0	65.5	262	590	1 049	1 328
2.25	148	590	1 327	2 360	2 987
5.0	328	1 314	2 958	5 258	6 655
10.0	655	2 622	5 900	10 490	13 276

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 H EXAMINATION OF WELDS USING ANGLE BEAM SEARCH UNITS

H-410 SCOPE

This Appendix describes a method of examination of welds using angle beam search units.

H-470 EXAMINATION

H-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.

H-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.

H-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.

(25) ### 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. When the component material is clad, the thickness of the cladding shall be at least as thick as the cladding on the part to be examined. 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 unknown or 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 different P-, A-, or F-numbers, the calibration block shall be clad with the same P-, A-, or F-numbers 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 (25)

(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.

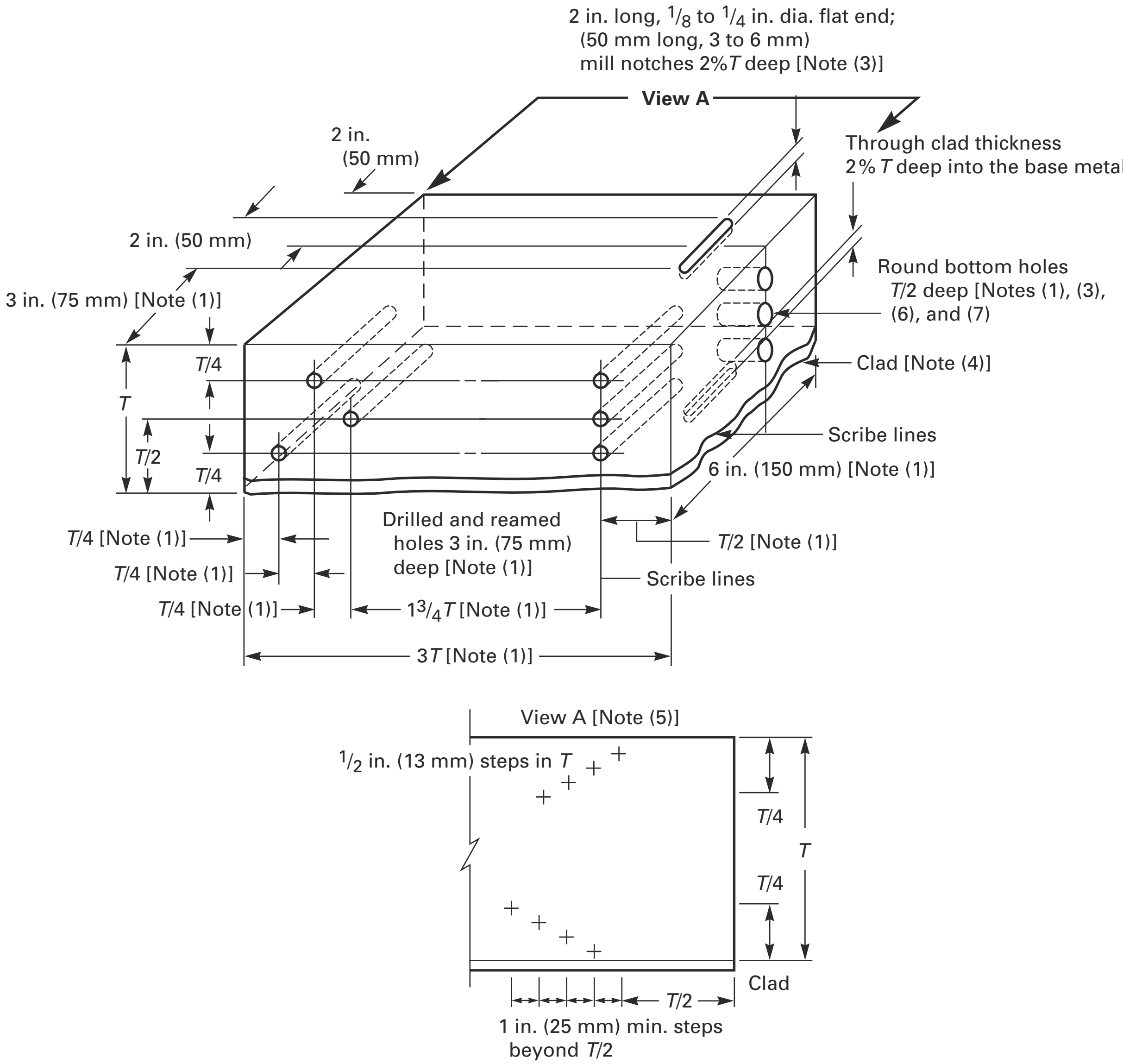
(c) Additional Reflectors. Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

(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 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

(25)

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)]
>2 through 4 (>50 through 100)	3 or *t* (75 or *t*)	3/16 (5)	3/8 (10)
>4 through 6 (>100 through 150)	5 or *t* (125 or *t*)	1/4 (6)	7/16 (11)
>6 through 8 (>150 through 200)	7 or *t* (175 or *t*)	5/16 (8)	1/2 (13)
>8 through 10 (>200 through 250)	9 or *t* (225 or *t*)	3/8 (10)	9/16 (14)
>10 through 12 (>250 through 300)	11 or *t* (275 or *t*)	7/16 (11)	5/8 (16)
>12 through 14 (>300 through 350)	13 or *t* (325 or *t*)	1/2 (13)	11/16 (17)
>14 (>350)	$t \pm 1$ ($t \pm 25$)	[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. (350 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 and the technique of Nonmandatory Appendix B, B-466 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.

radius to be examined is greater than the critical radius determined by Nonmandatory Appendix G. 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 G-461.

(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

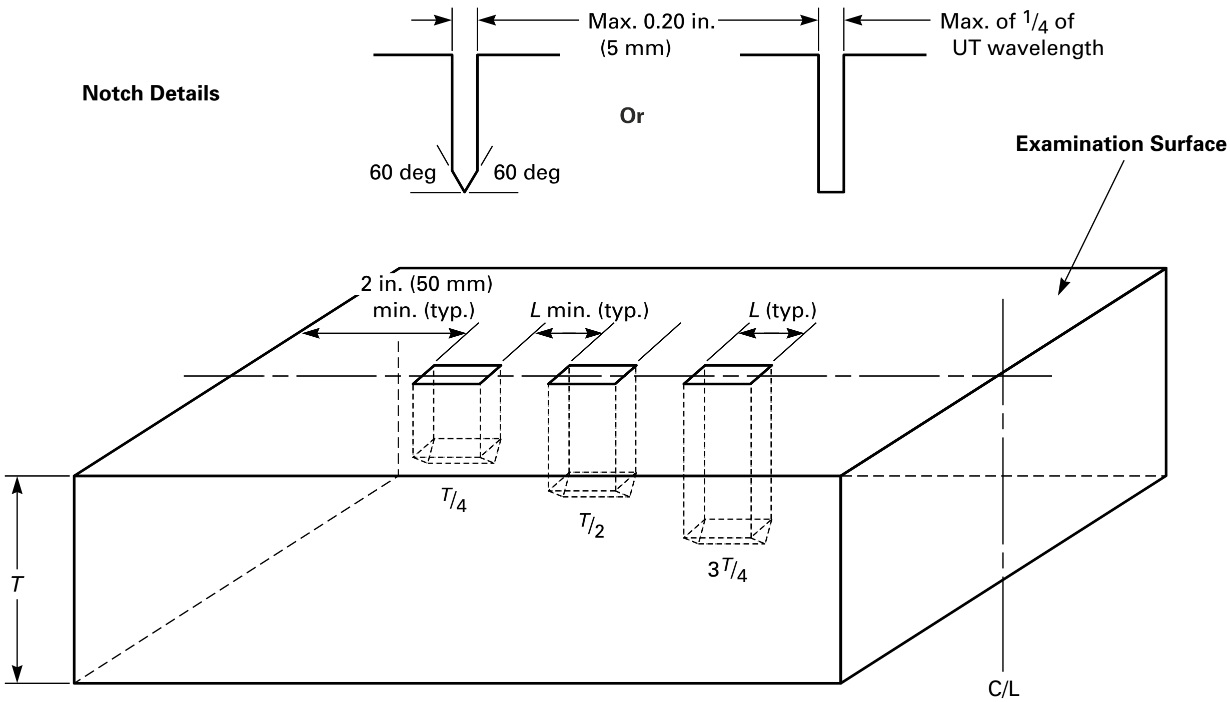
(c) D-scan (non-parallel scan) techniques with the notches offset by varying amounts to either side of being centered.

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 back wall 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:

$$h = \left[\left(c \left(t_d + t_p \right) / 2 \right)^2 - s^2 \right]^{1/2} - d$$

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 = time of flight at depth d
t_p = 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.[11] 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.

M-461.2.4 Sweep Readings. The sweep now represents 2 in. (50 mm) of sound path distance.

Figure M-461.1
Sweep Range (Side-Drilled Holes)

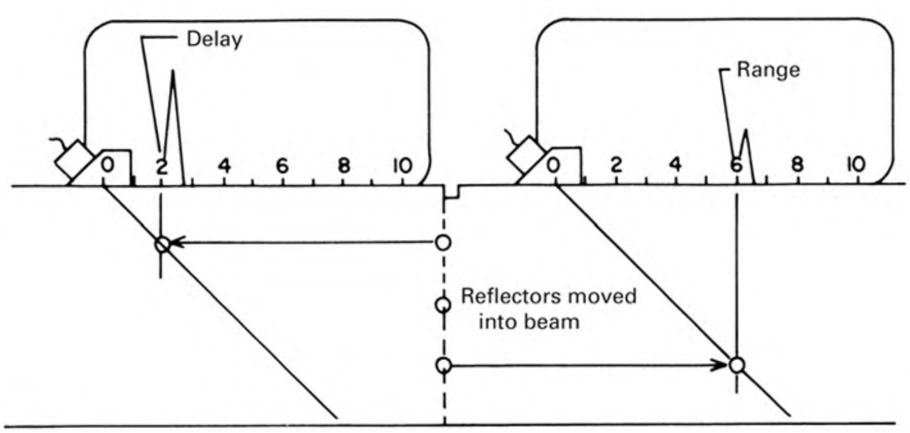
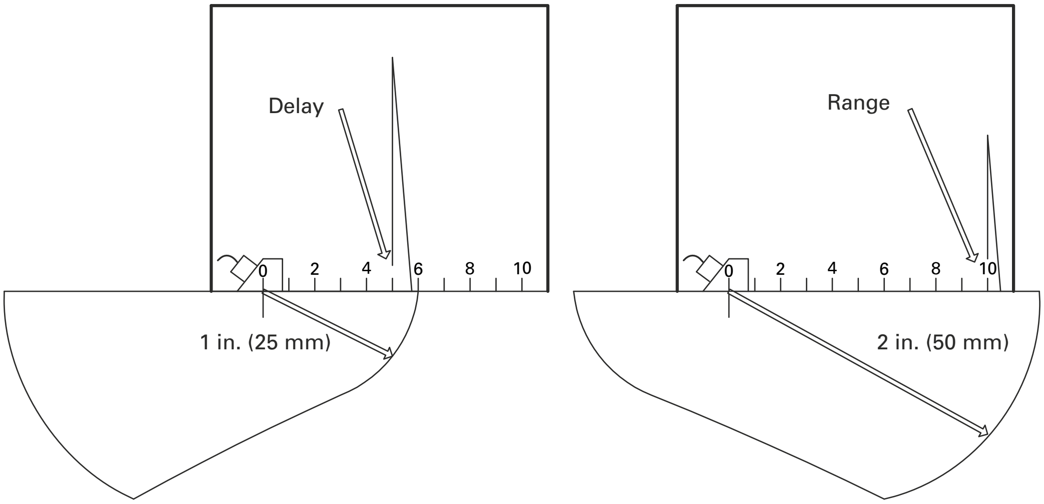


Figure M-461.2
Sweep Range (Cylindrical Surfaces)



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.

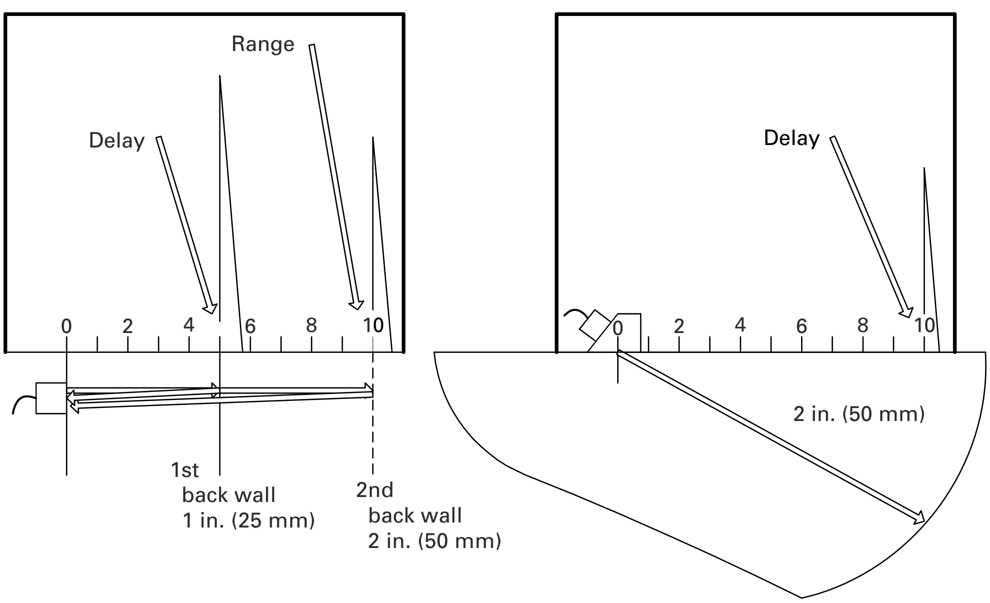
M-461.3.2 Delay Control Adjustment. Adjust the left edge of the first back-wall indication to line 5 on the screen with the delay control.

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.

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

Figure M-461.3
Sweep Range (Straight Beam Search Unit)



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.

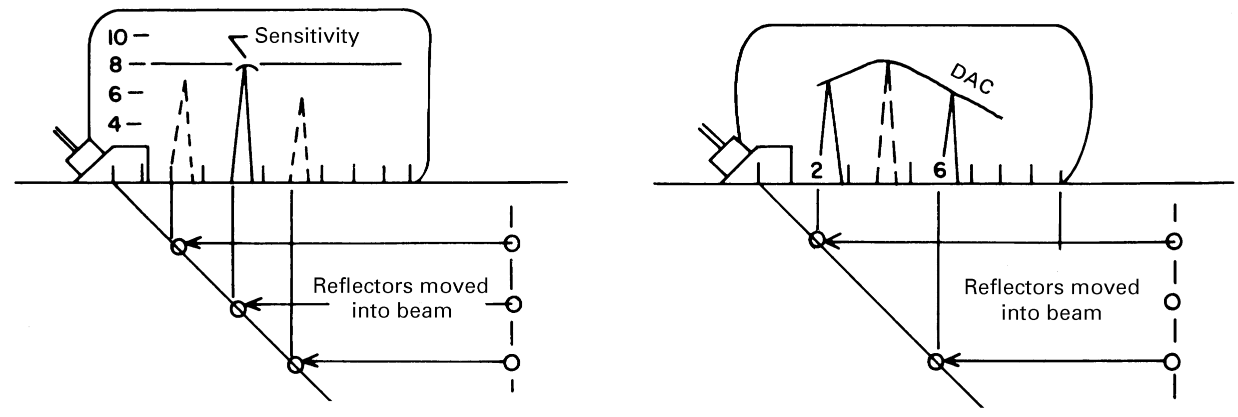
(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height. This is the primary reference level. Mark the peak of this indication on the screen.

(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 back-wall 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 back-wall signal.

(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 back-wall 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.

(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 back-wall signal is the strong

Figure N-421(a)
Schematic Showing Waveform Transformation Into Grayscale

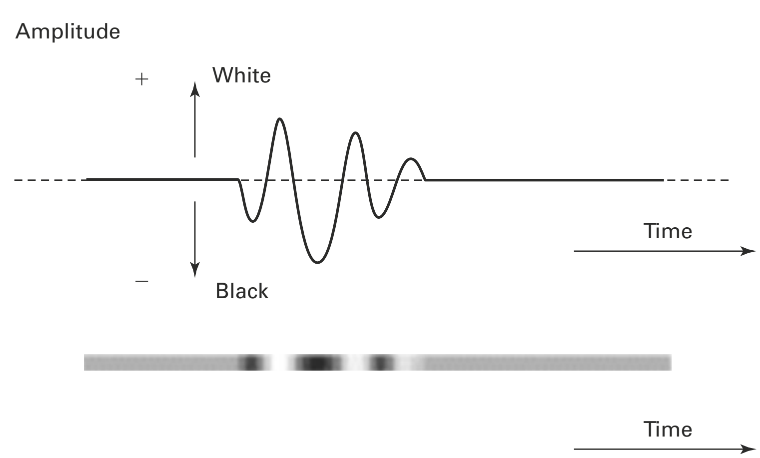
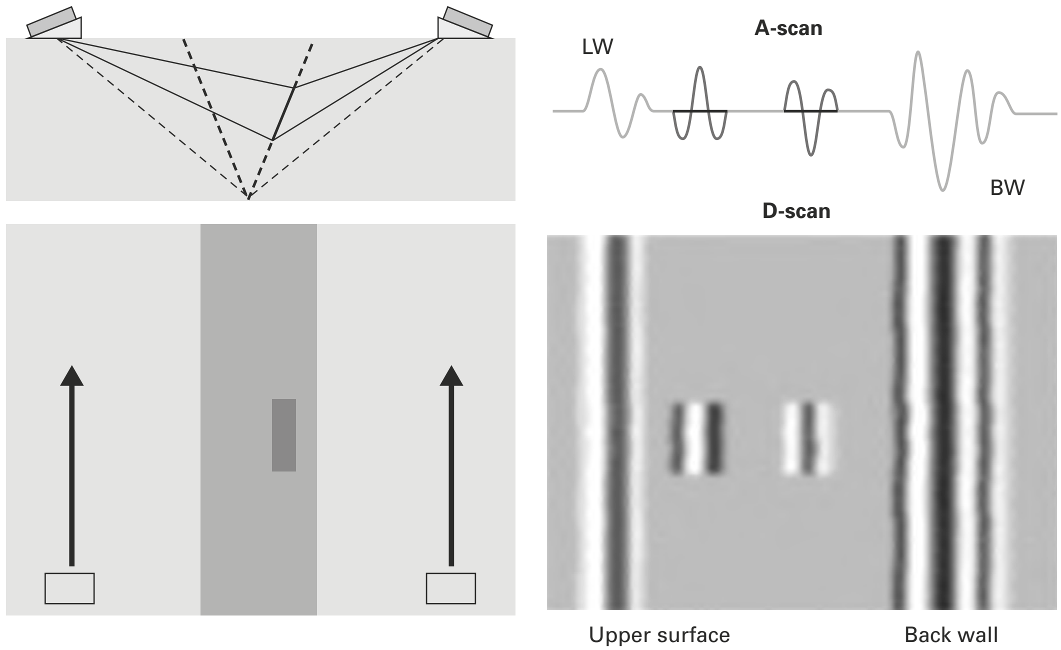


Figure N-421(b)
Schematic Showing Generation of Grayscale Image From Multiple A-Scans



multicycle pulse at right. The flaws show as multicycle gray and white reflections between the lateral and back-wall 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 back-wall signals (I.D.), with "noise." There is also ultrasonic information available past the back wall (typically shear wave diffractions), but this is generally not used.

Figure N-421(c)
Schematic Showing Standard TOFD Setup and Display With Waveform and Signal Phases

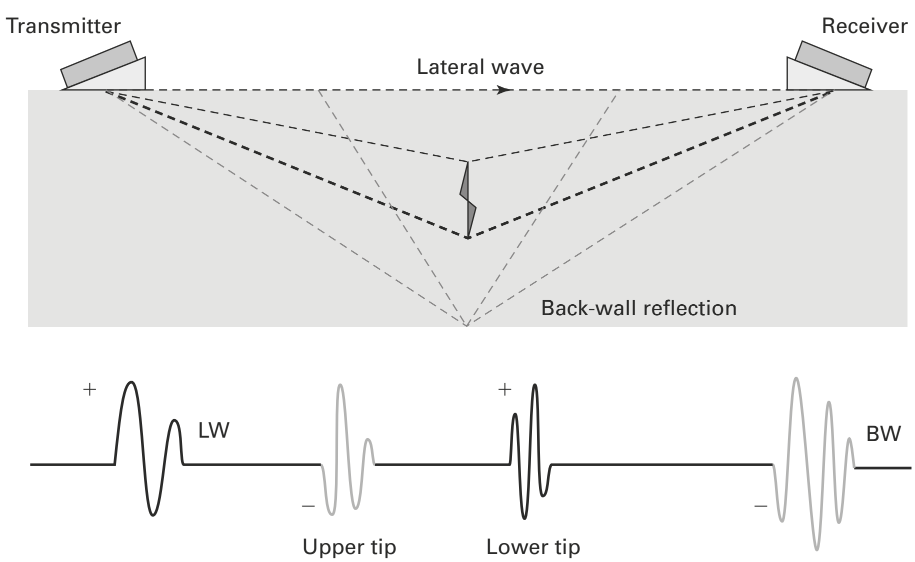
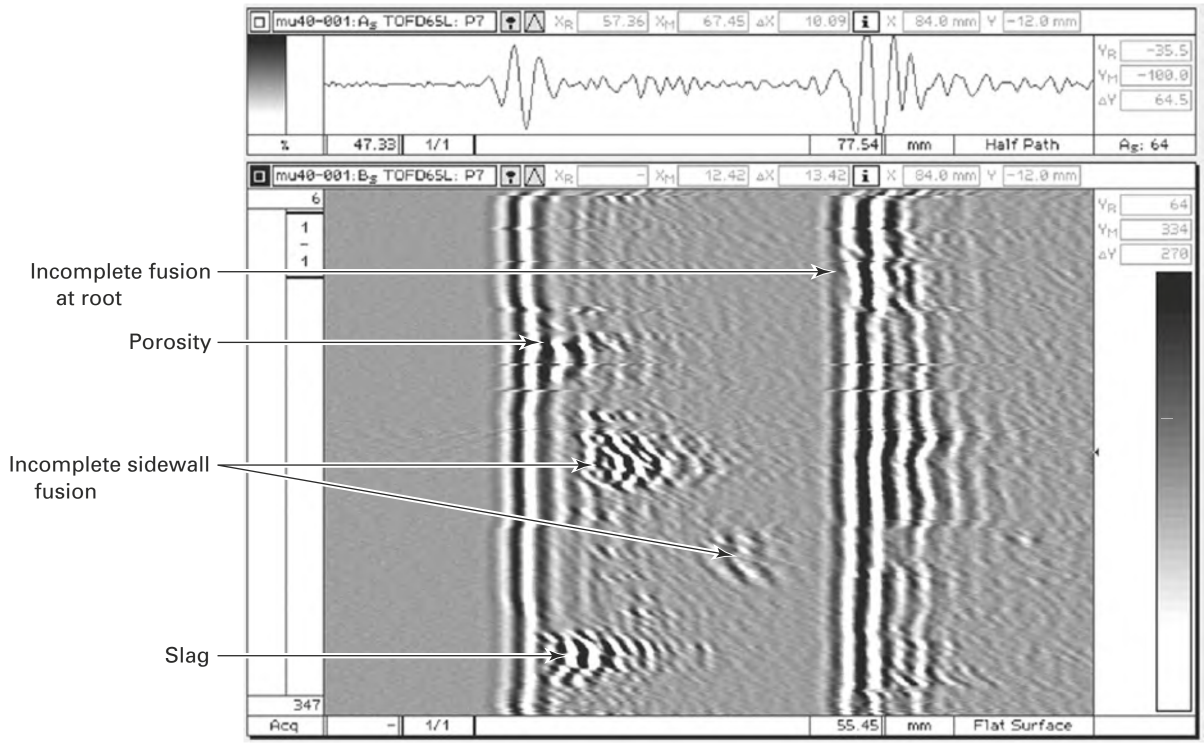


Figure N-421(d)
TOFD Display With Flaws and Displayed A-Scan



GENERAL NOTE: Time is horizontal and the axis of motion is vertical.

N-450 PROCEDURE

N-451 MEASUREMENT TOOLS

TOFD variables are probe spacing, material thickness, sound velocity, transducer delay, and lateral wave transit and back-wall 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 back-wall (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 back-wall 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 back wall. Exact error values will depend on the inspection parameters.

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.

Figure N-451
Measurement Tools for Flaw Heights

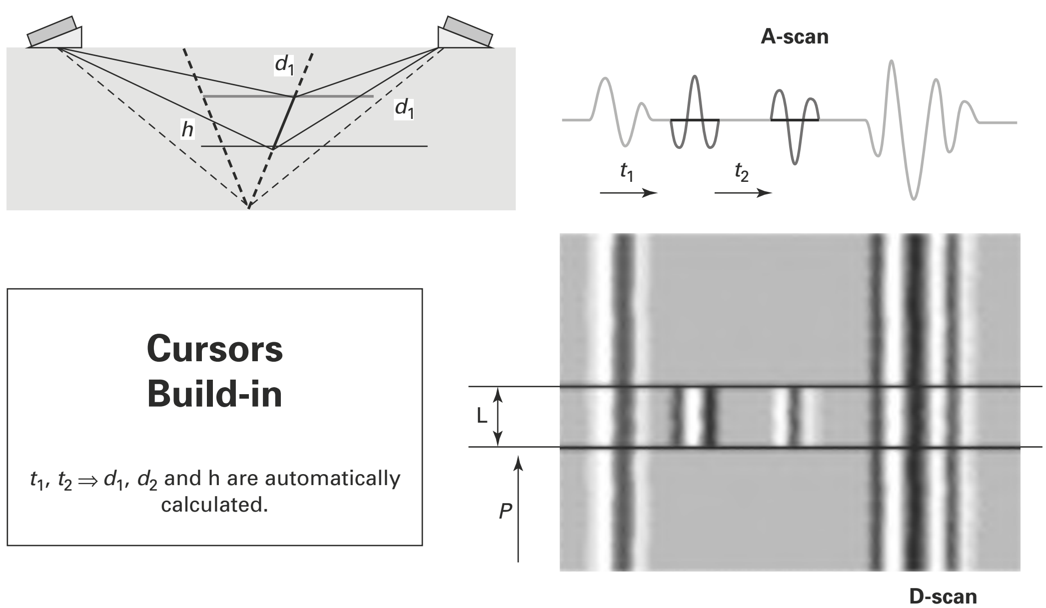


Figure N-452(a)
Schematic Showing the Detection of Off-Axis Flaws

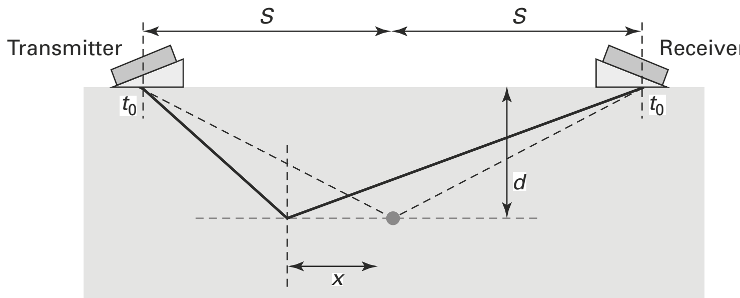
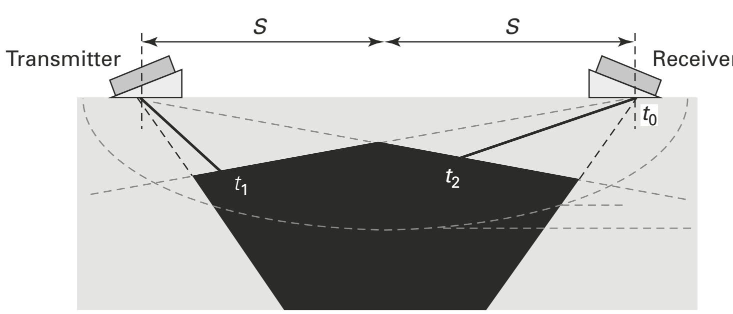


Figure N-452(b)
Measurement Errors From Flaw Position Uncertainty



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 back wall.

Figure N-453
TOFD Image Showing Hyperbolic "Tails" From the Ends of a Flaw Image Used to Measure Flaw Length

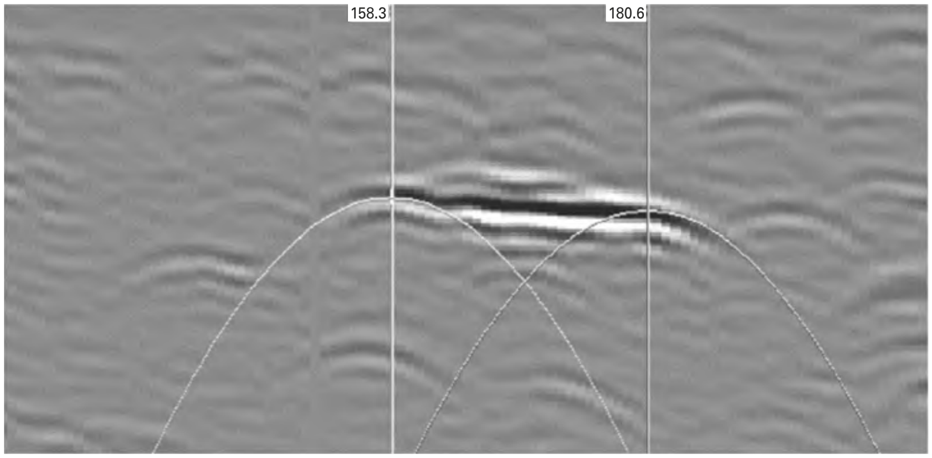


Figure N-454(a)
TOFD Image Showing Top and Bottom Diffracted Signals From Midwall Flaw and A-Scan Interpretation

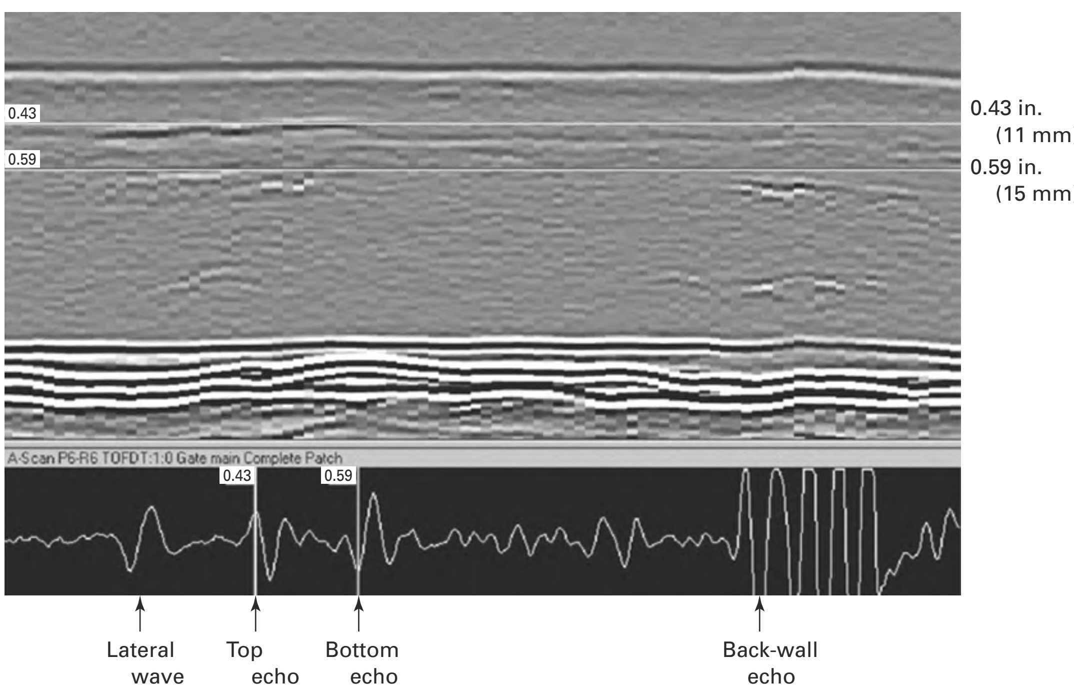
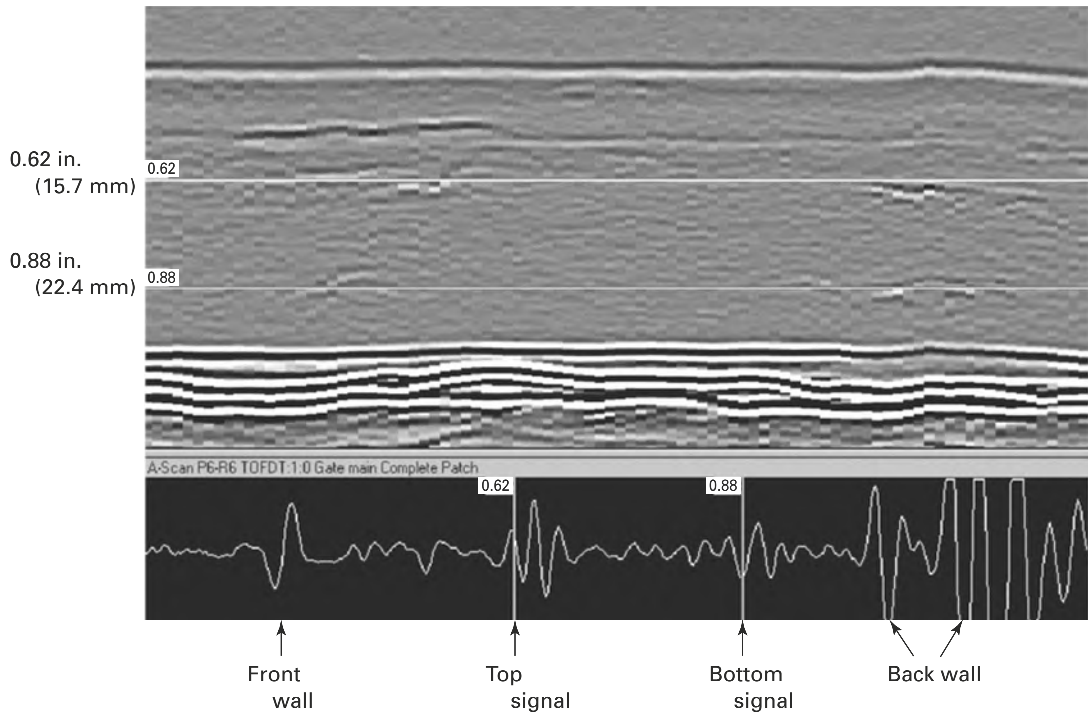


Figure N-454(b)
TOFD Image Showing Top and Bottom Diffracted Signals From Centerline Crack and A-Scan Interpretation



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 back-wall 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 on the transducer frequency and damping). Point flaws usually show parabolic “tails” where the signal drops off towards the back wall.

(b) Inside (I.D.) far-surface-breaking flaws [Figure N-481(b)] shows no interruption of the lateral wave, a signal near the back wall, and a related interruption or break of the back wall (depending on flaw size).

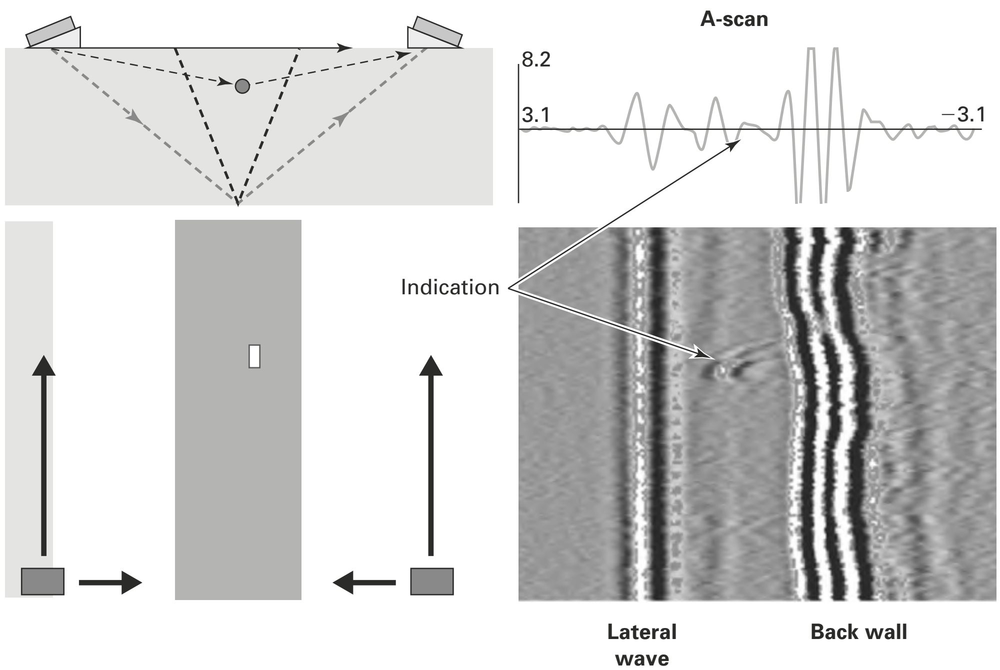
(c) Near-surface-breaking flaws [Figure N-481(c)] shows perturbations in the lateral wave. The flaw breaks the lateral wave, so TOFD can be used to determine if the flaw is surface-breaking or not. The lower signal can then be used to measure the depth of the flaw. If the flaw is not surface-breaking, 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 back-wall 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-453).

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 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

Figure N-481(a)
Schematics of Image Generation, Scan Pattern, Waveform, and TOFD Display Showing the Image of the Point Flaw



from the back-wall 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 back-wall signal, the back wall 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 back-wall 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

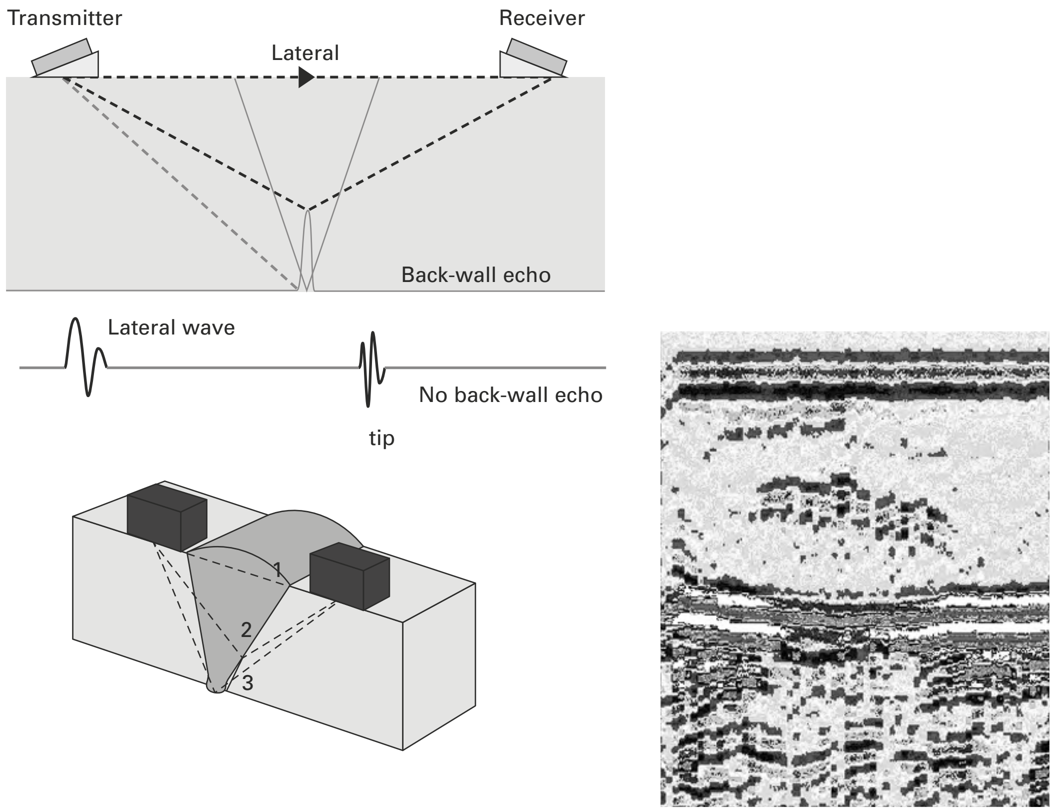


Figure N-481(c)
Schematics of Image Generation, Flaw Location, and TOFD Display Showing the Image of the Outside (OD) Surface-Breaking Flaw

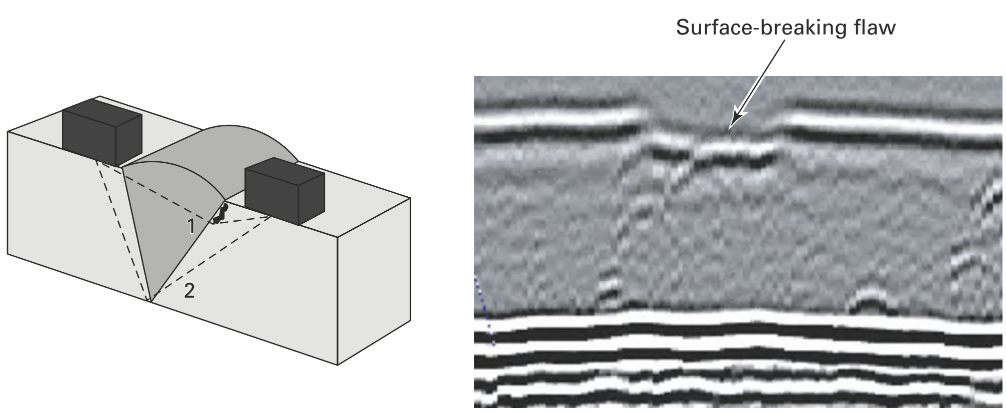


Figure N-481(d)
Schematics of Flaw Location, Signals, and TOFD Display Showing the Image of the Midwall Flaw

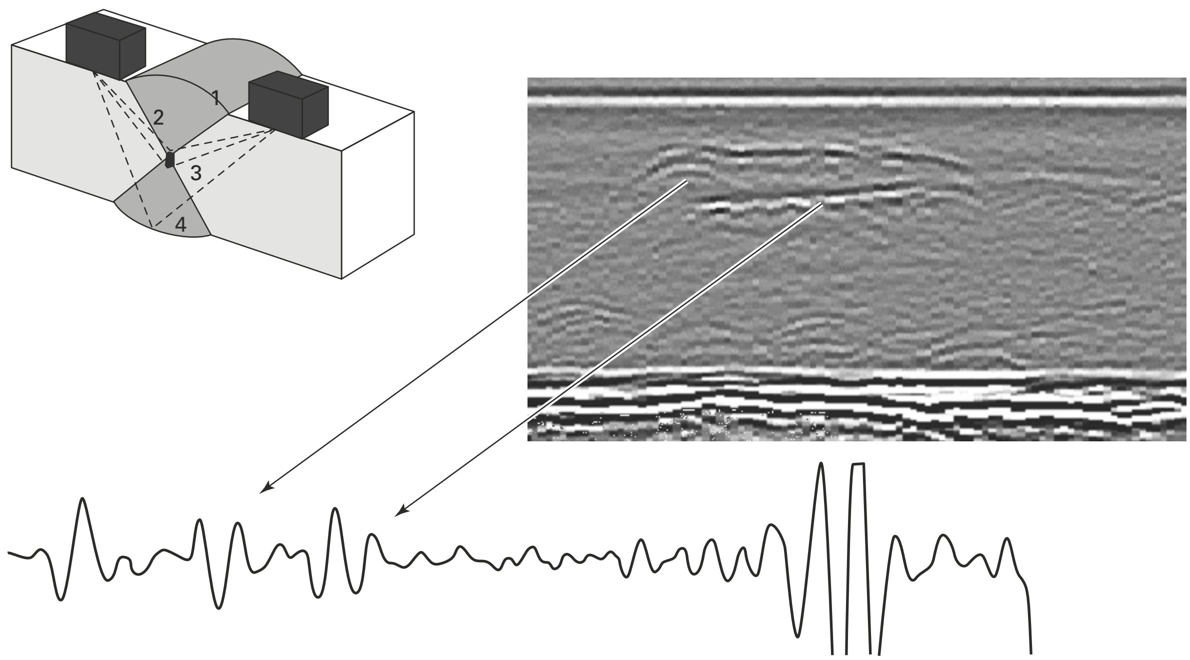


Figure N-481(e)
Flaw Location and TOFD Display Showing the Image of the Lack of Root Penetration

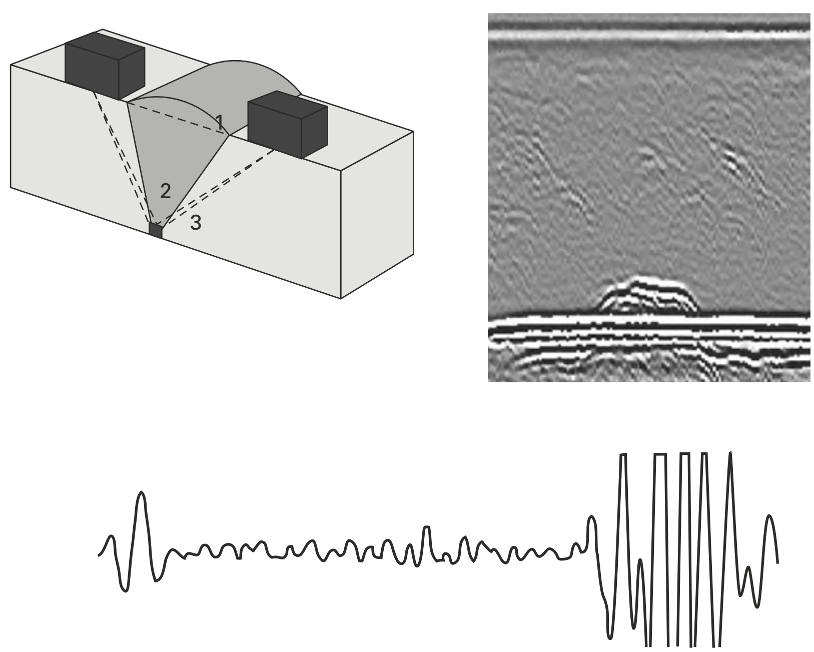
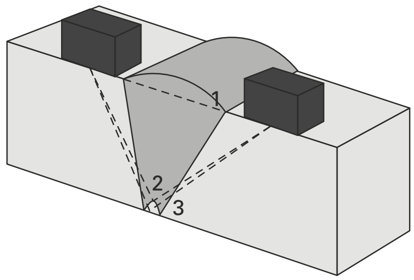


Figure N-481(f)
Flaw Location and TOFD Display Showing the Image of the Concave Root Flaw



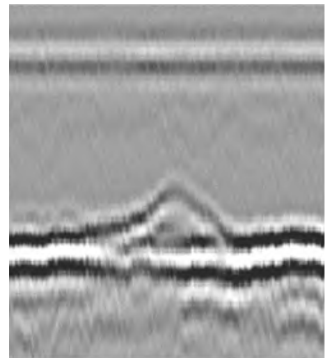
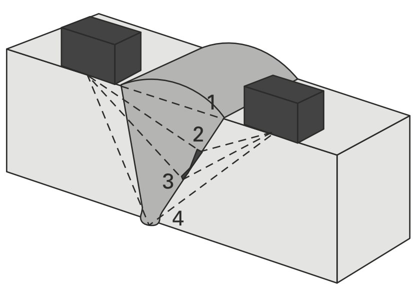
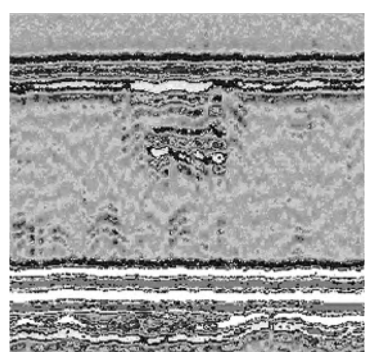


Figure N-481(g)
Flaw Location, TOFD Display Showing the Image of the Midwall Lack of Fusion Flaw, and the A-Scan





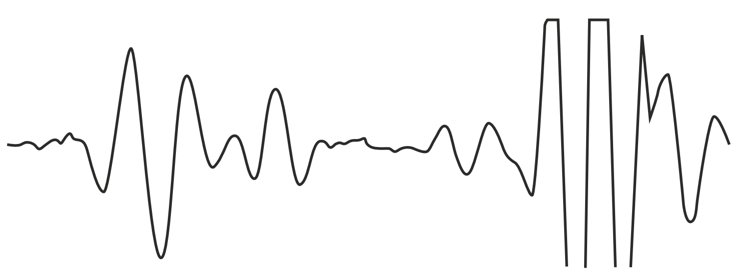


Figure N-481(h)
Flaw Location and TOFD Display Showing the Image of the Porosity

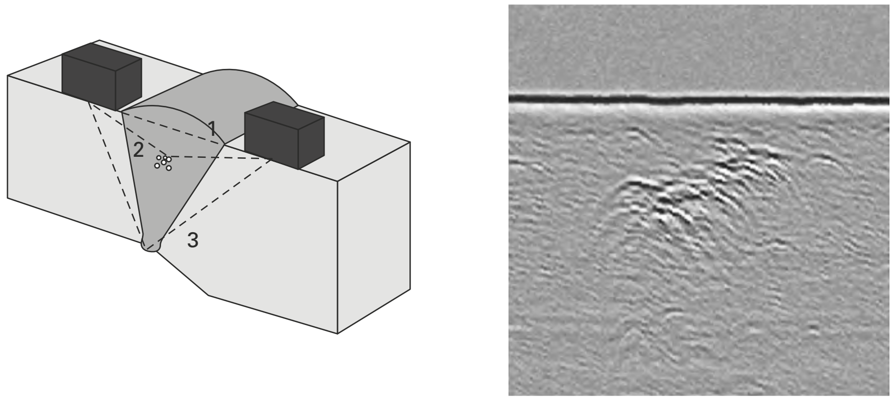


Figure N-481(i)
Flaw Location and TOFD Display Showing the Image of the Transverse Crack

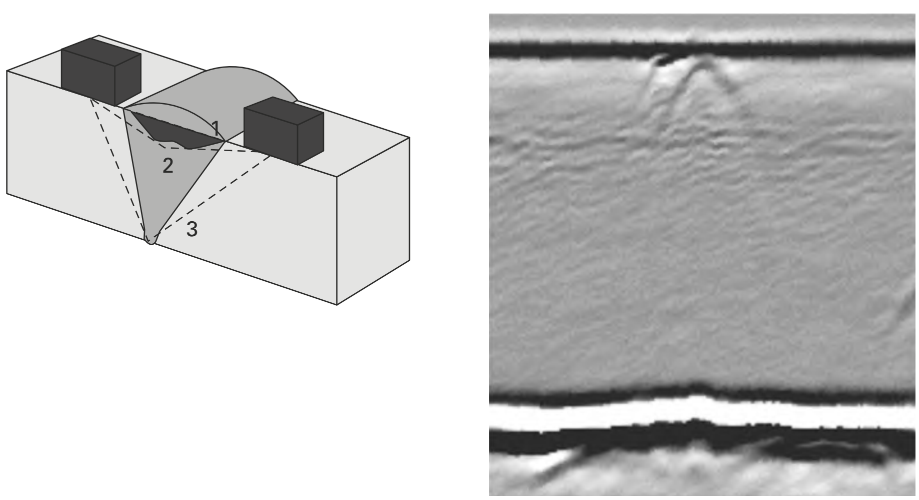
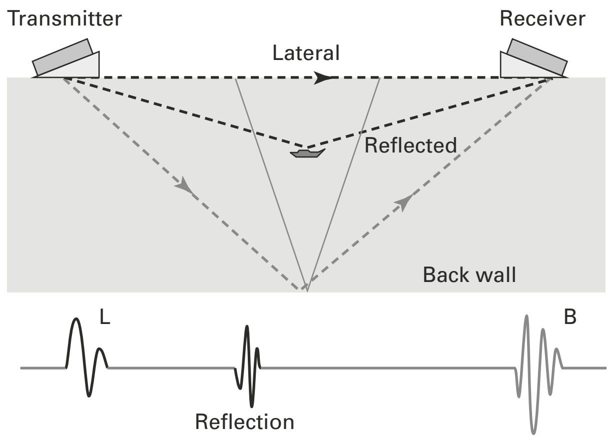
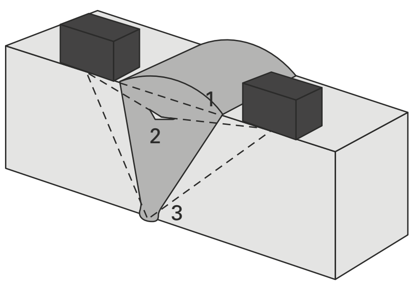
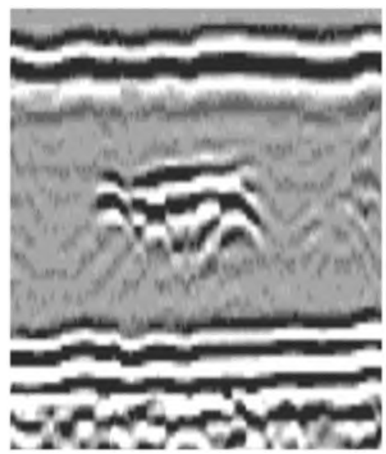


Figure N-481(j)
Schematics of Image Generation, Flaw Location, and TOFD Display Showing the Image of the Interpass Lack of Fusion







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 back wall. This is not surprising in the back-wall 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 back-wall dead zone.

N-482.2 Plate 2 [Figure N-482(b)]. Figure N-482(b) shows that:

(a) all four flaws are detectable

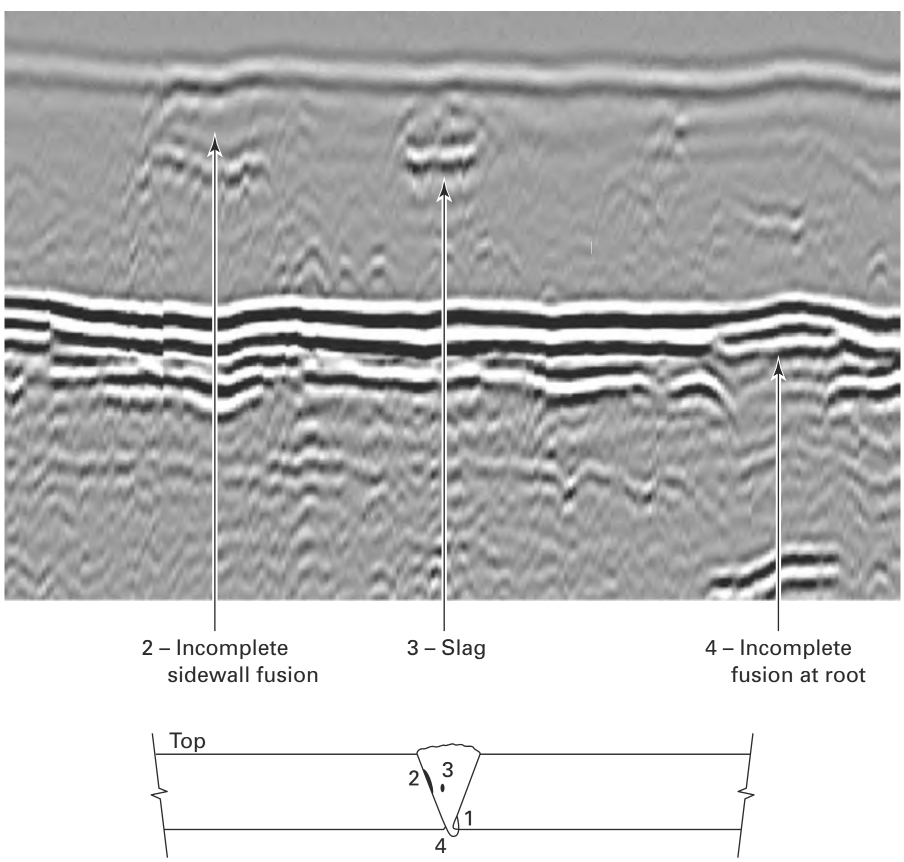
(b) the incomplete fusion at the root shows up clearly in this scan because it is deeper. Both the back-wall perturbation and the flaw tip signals are clear.

(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 back-wall 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.

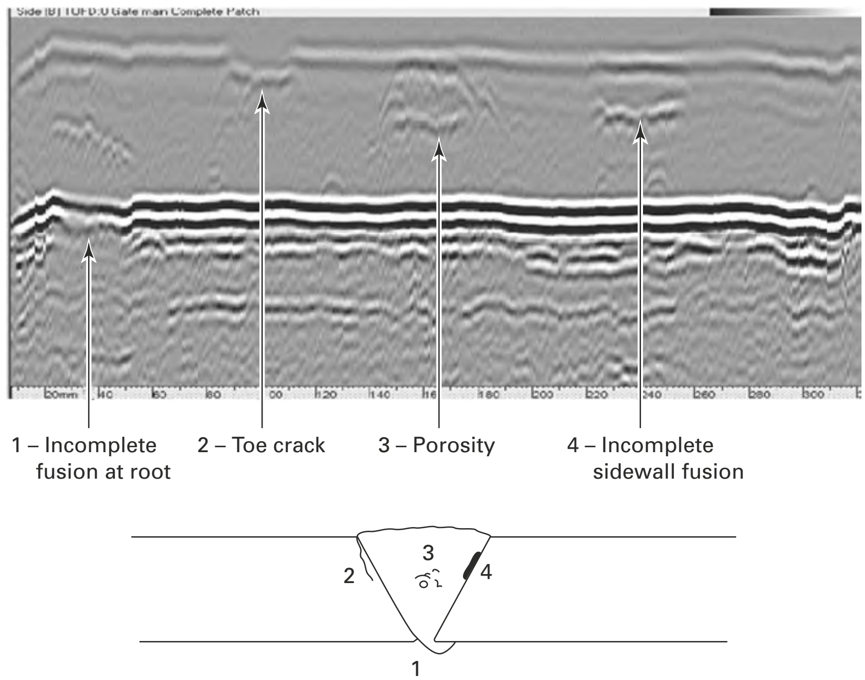
(e) the incomplete sidewall fusion is clearly visible and could be easily sized using cursors.

Figure N-482(a)
Schematic of Flaw Locations and TOFD Image Showing the Lateral Wave, Back Wall, 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, Back Wall, 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 back wall, if required. Typically, the best signal to use as a guide is the first (longitudinal wave) back wall, 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 back wall is not. Any inside (I.D.) near-back-wall 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 back wall, and the second signal is the shear wave back wall. 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 back-wall 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

Figure N-483(a)
Acceptable Noise Levels, Flaws, Lateral Wave, and Longitudinal Wave Back Wall

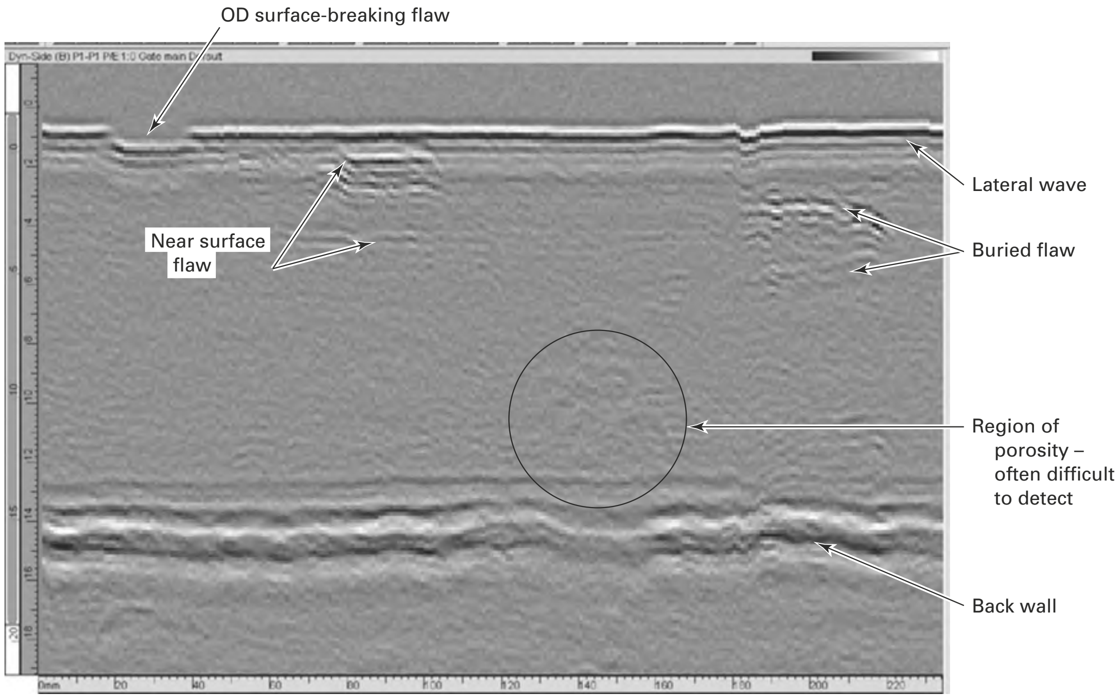


Figure N-483(b)
TOFD Image With Gain Too Low

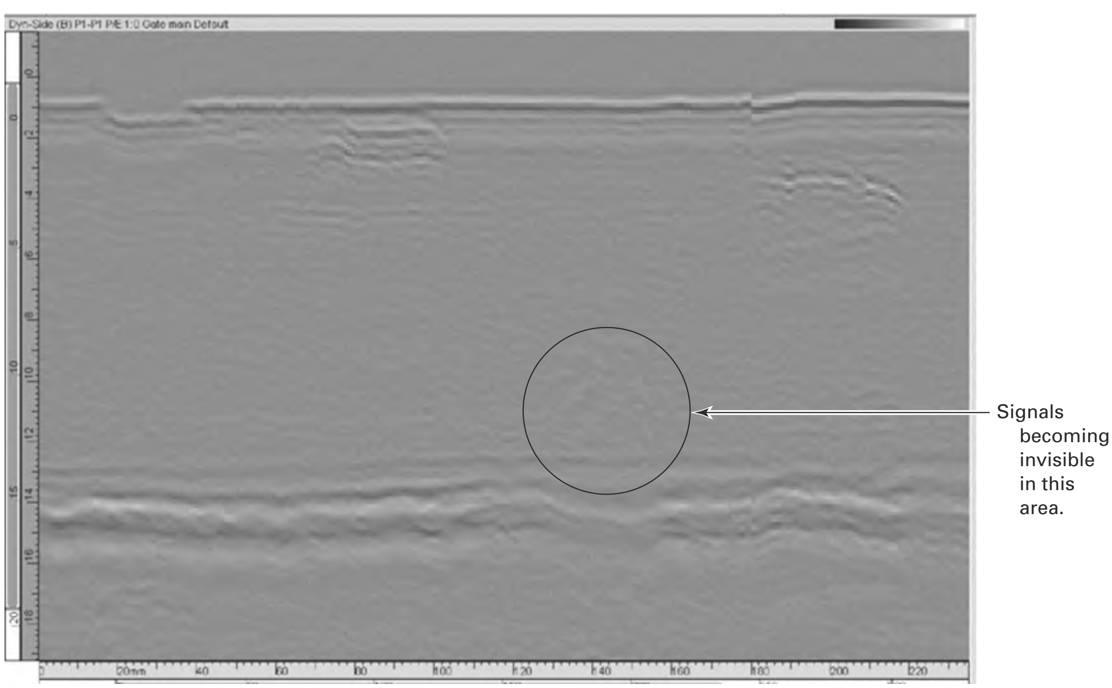


Figure N-483(c)
TOFD Image With Gain Set Too High

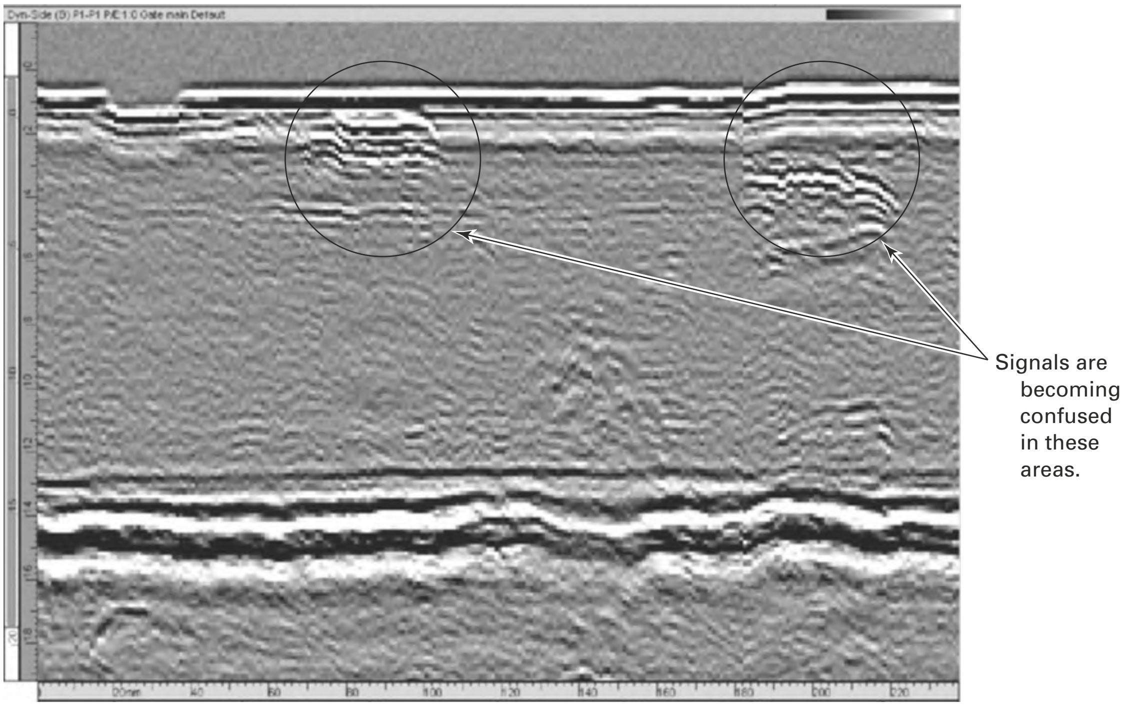


Figure N-483(d)(1)
TOFD Image With the Gate Set Too Early

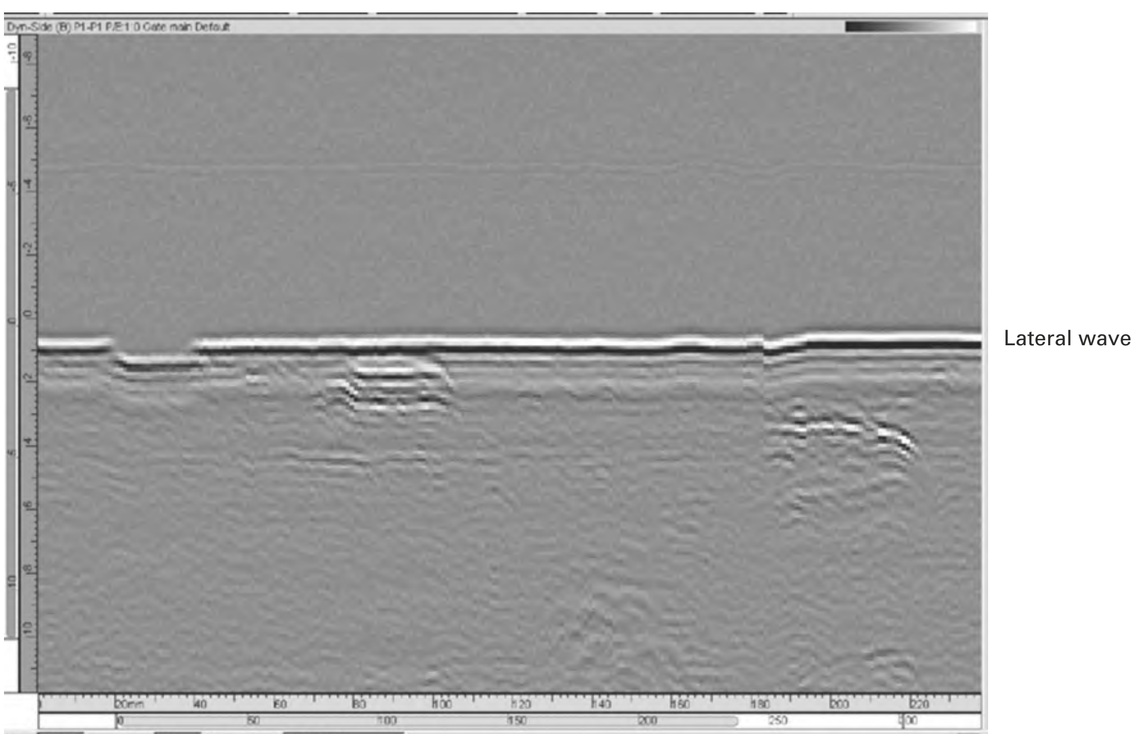
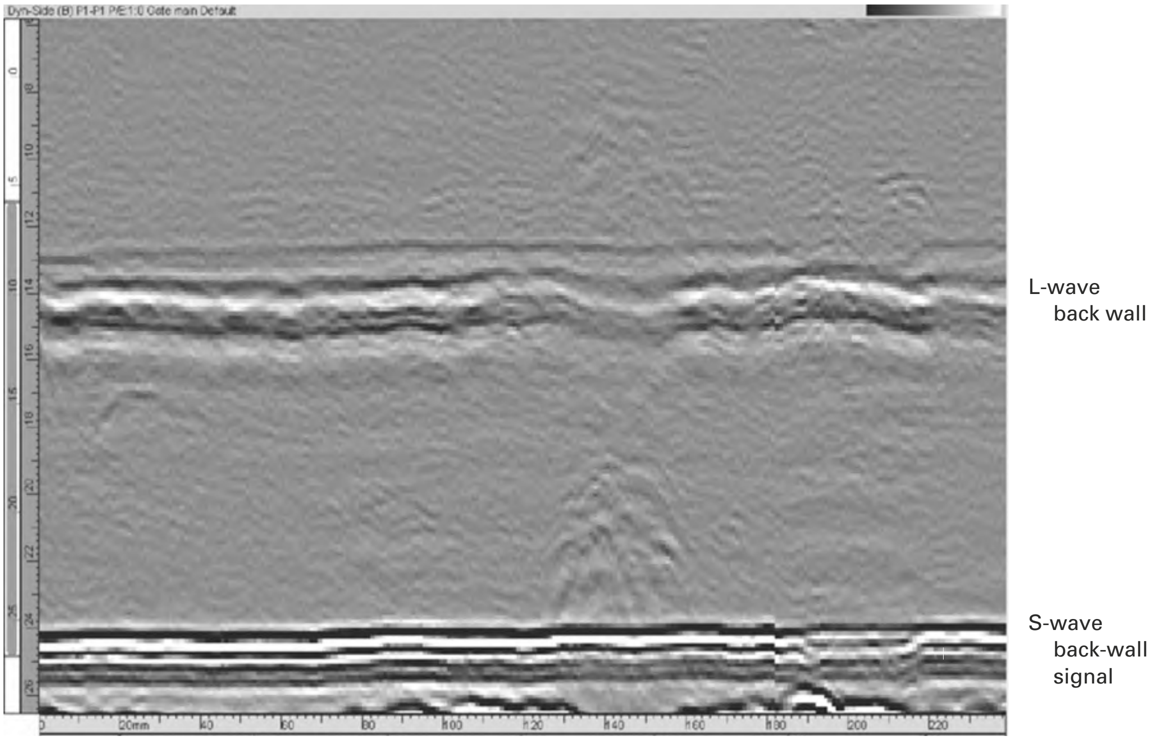


Figure N-483(d)(2)
TOFD Image With the Gate Set Too Late



signal that 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 back wall to clarify interpretation.

(e) Incorrect (too far apart) transducer separation [Figure N-483(e)] results in the back-wall 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 back wall 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(d)(3)
TOFD Image With the Gate Set Too Long

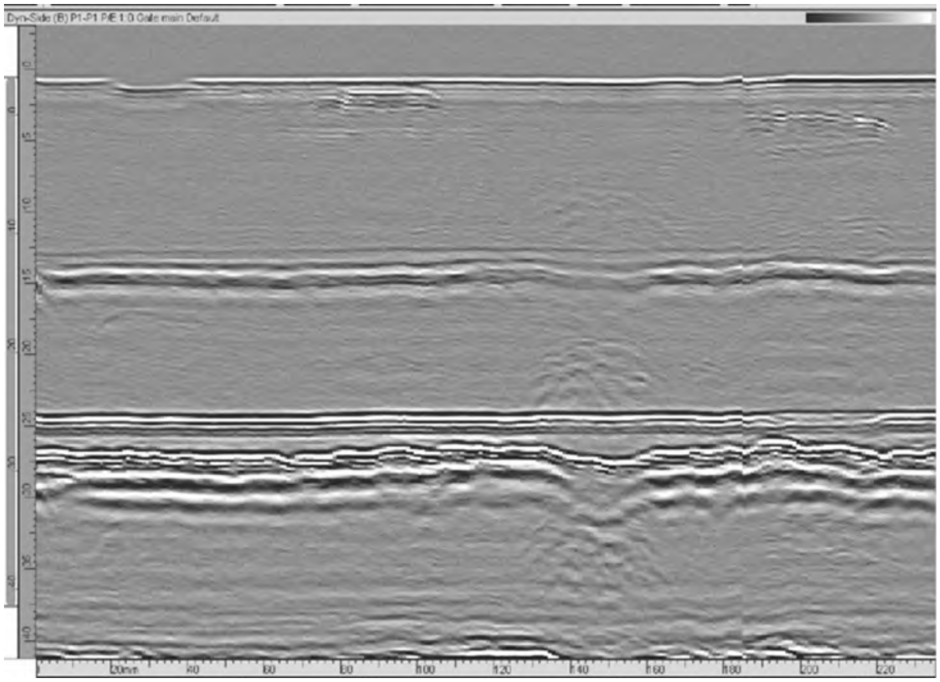


Figure N-483(e)
TOFD Image With Transducers Set Too Far Apart

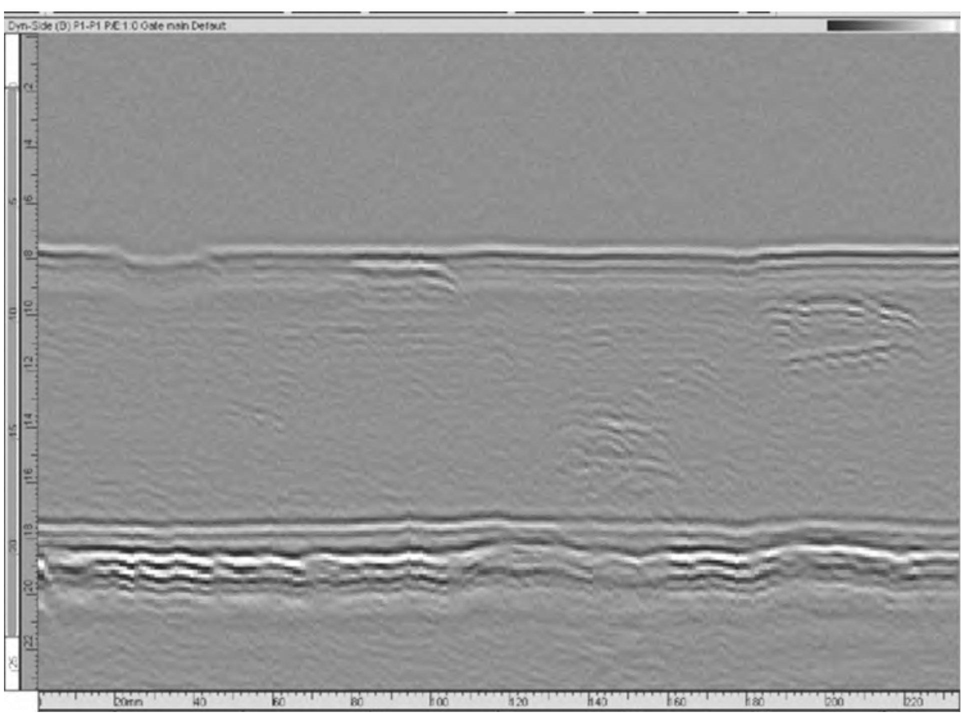


Figure N-483(f)
TOFD Image With Transducers Set Too Close Together

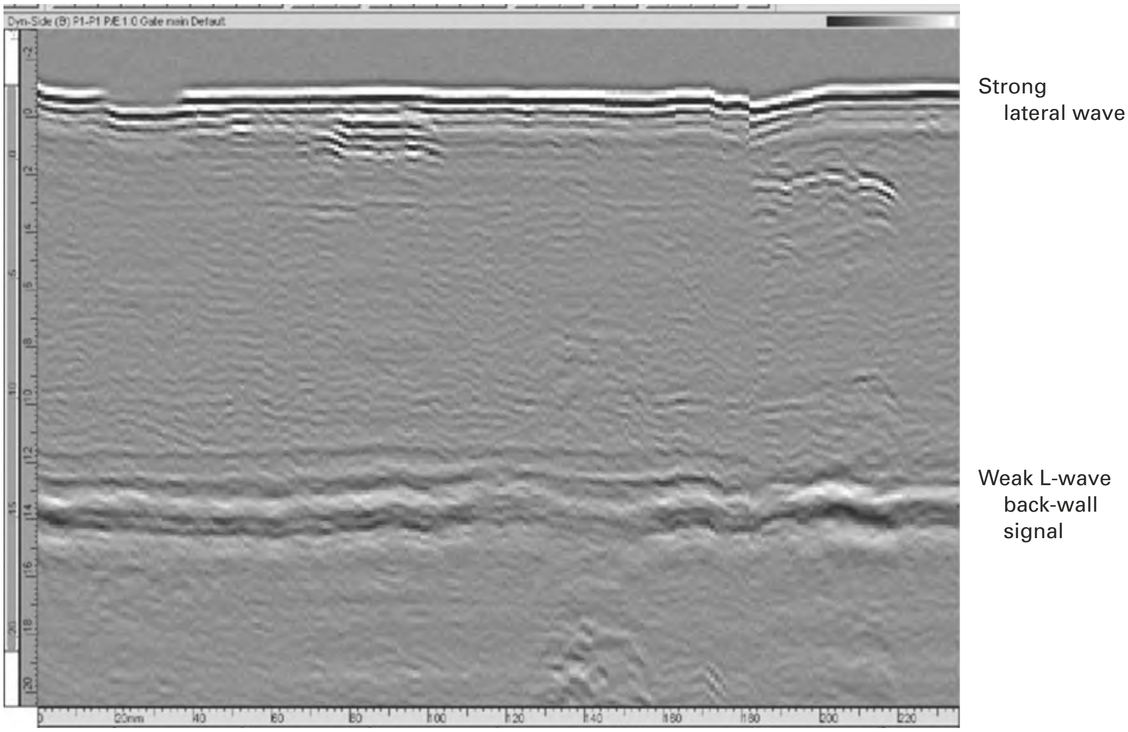


Figure N-483(g)
TOFD Image With Transducers Not Centered on the Weld Axis

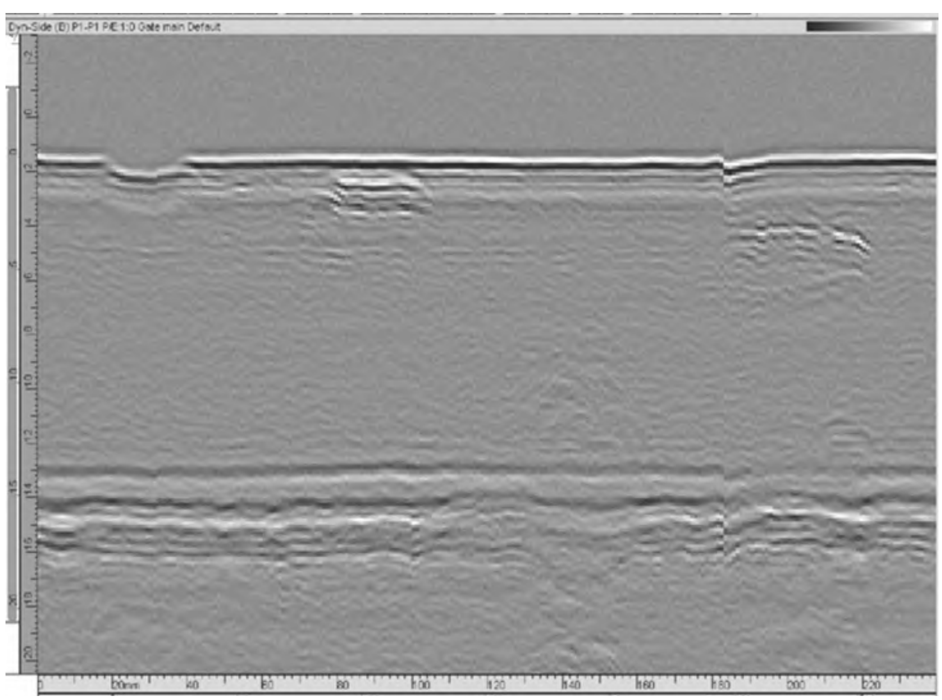
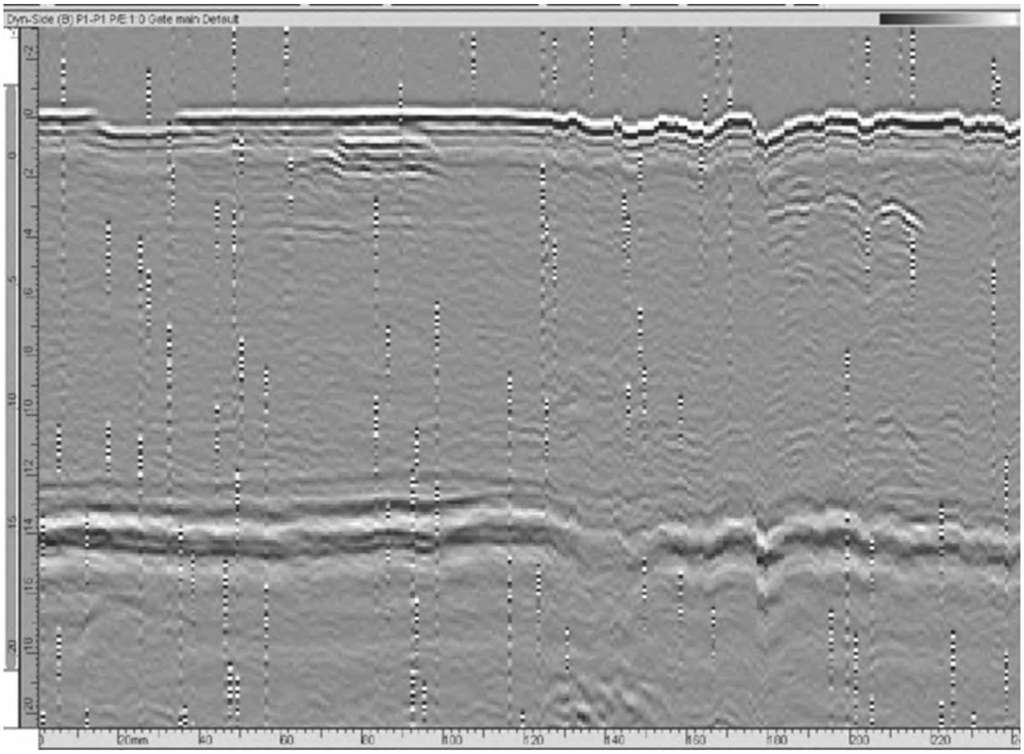


Figure N-483(h)
TOFD Image Showing Electrical Noise Interference



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

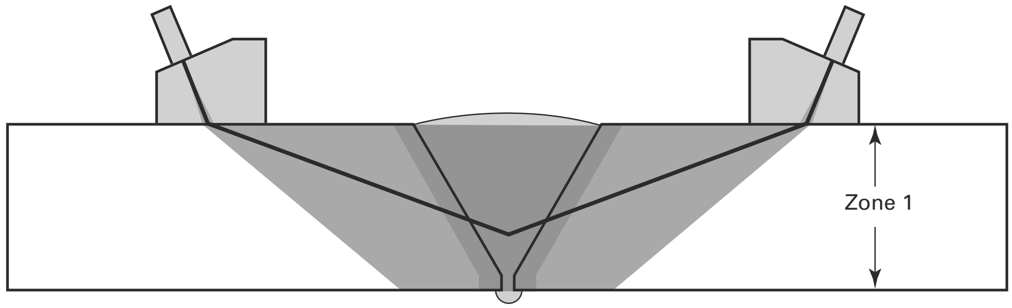


Figure O-470(b)
Example of a Two Zone TOFD Setup (Equal Zone Heights)

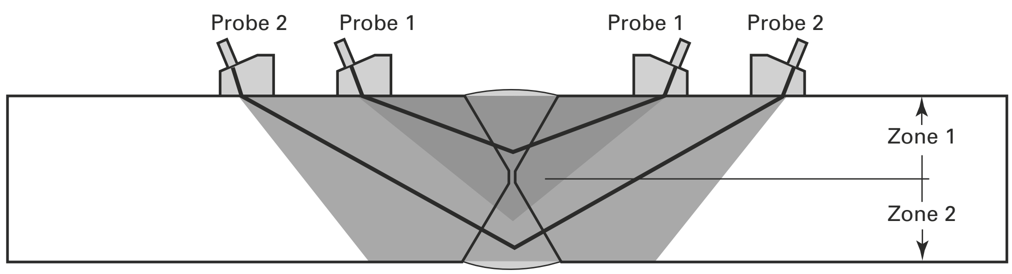


Figure O-470(c)
Example of a Three Zone TOFD Setup (Unequal Zone Heights With Zone 3 Addressed by Two Offset Scans)

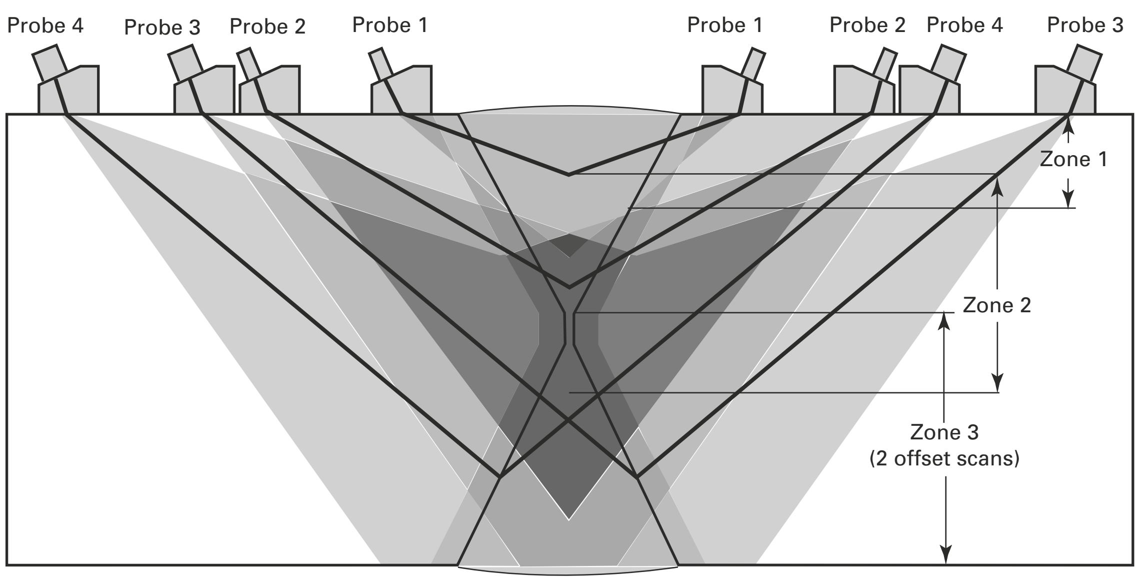
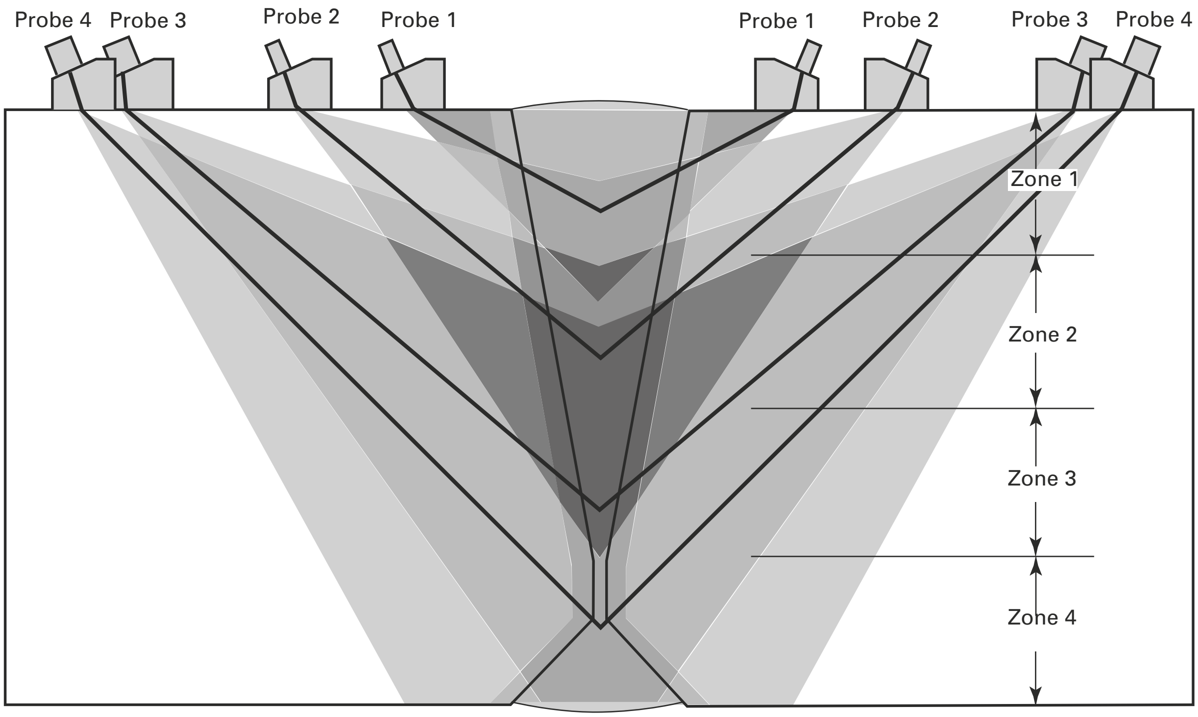


Figure O-470(d)
Example of a Four Zone TOFD Setup (Equal Zone Heights)



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.[16] 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

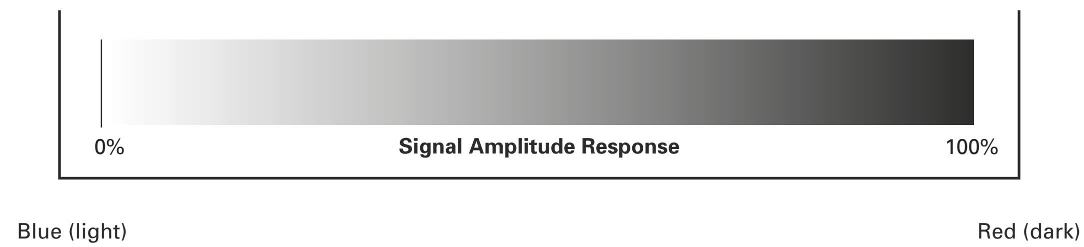


Figure P-421-2
Scan Pattern Format

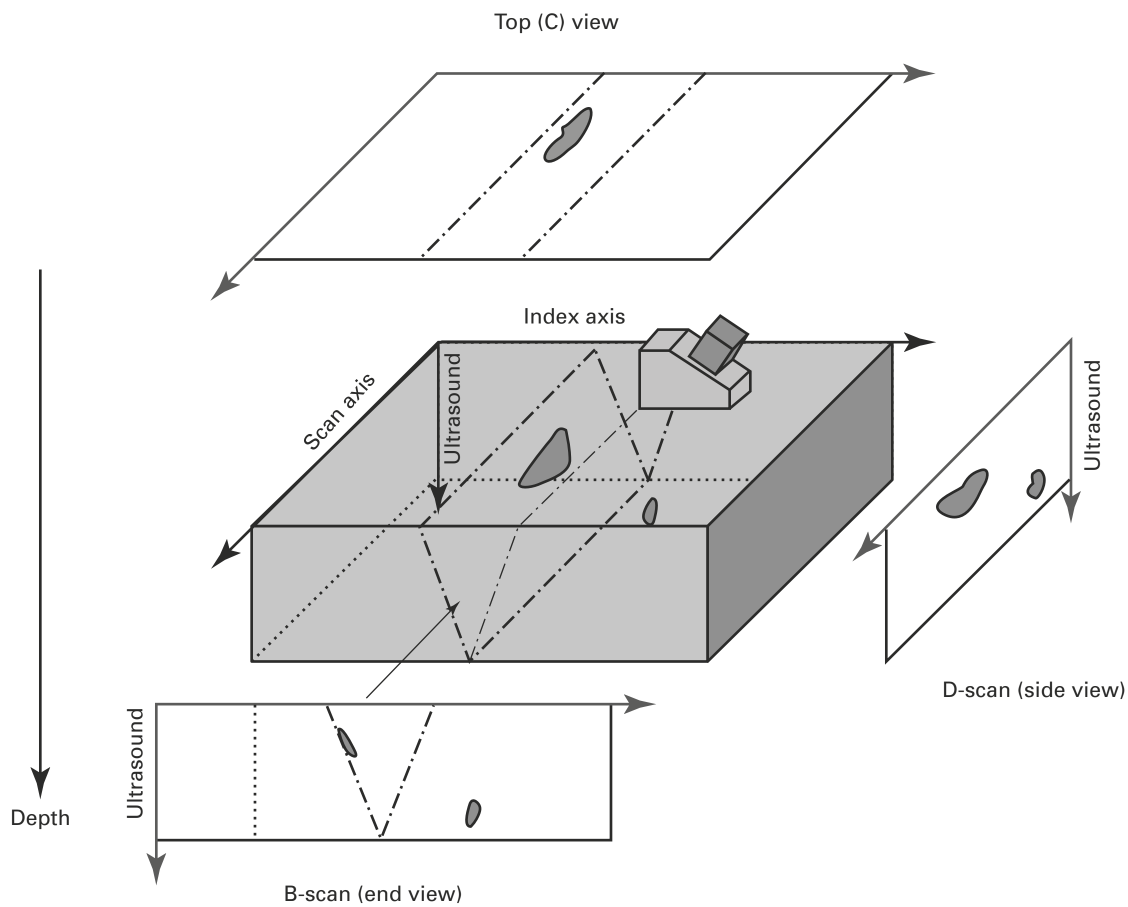


Figure P-421-3
Example of an E-Scan Image Display

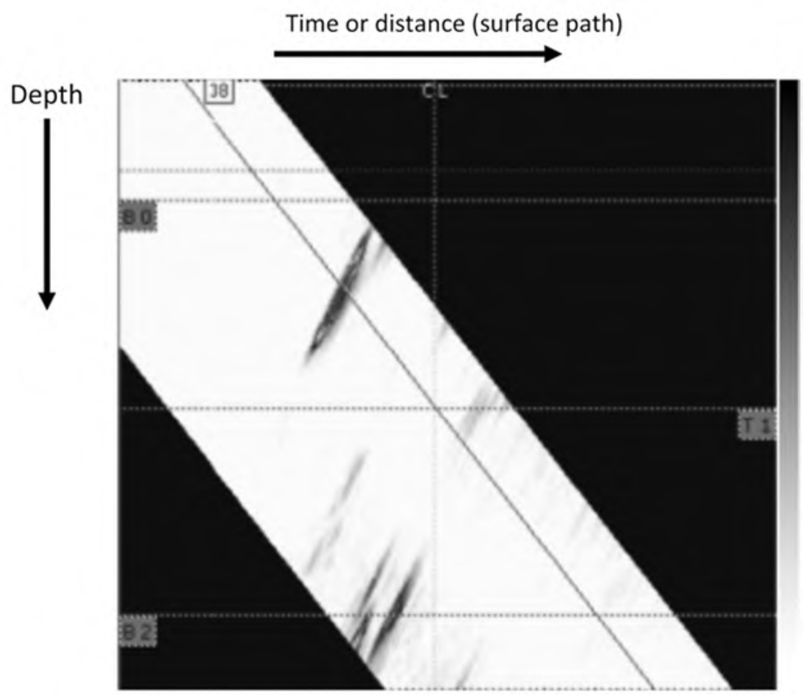


Figure P-421-4
Example of an S-Scan Image Display

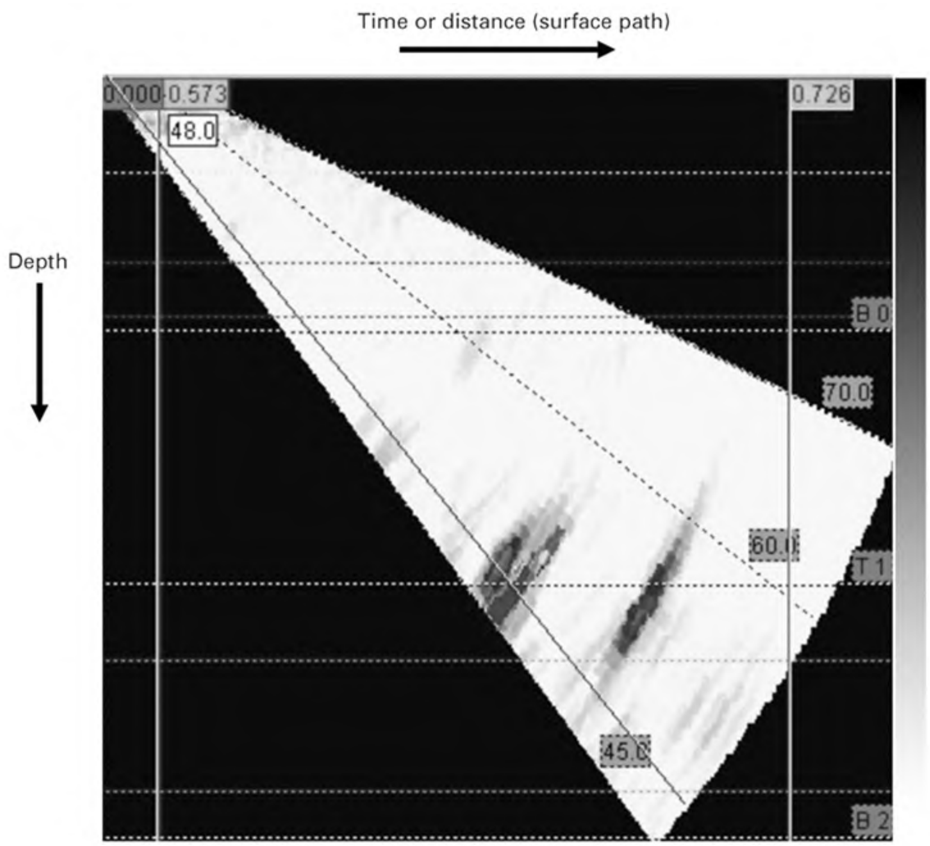


Figure P-452.1
Flaw Length Sizing Using Amplitude Drop Technique and the Vertical Cursors on the C-Scan Display

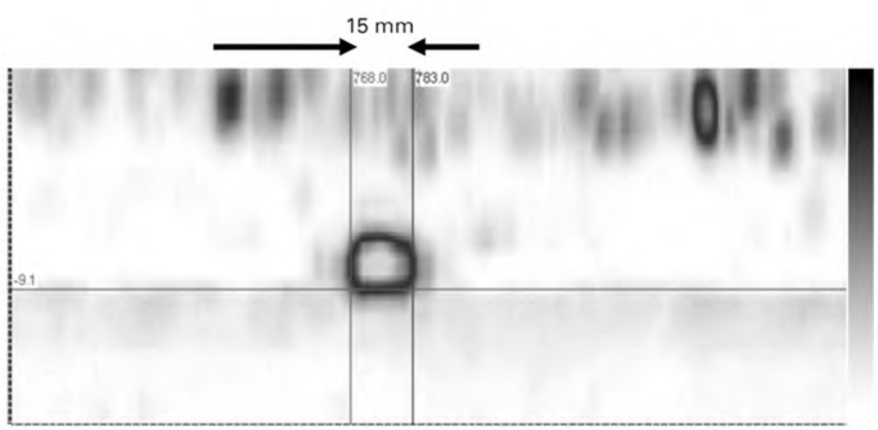


Figure P-452.2-1
Scan Showing Flaw Height Sizing Using Amplitude Drop Technique and the Horizontal Cursors on the B-Scan Display

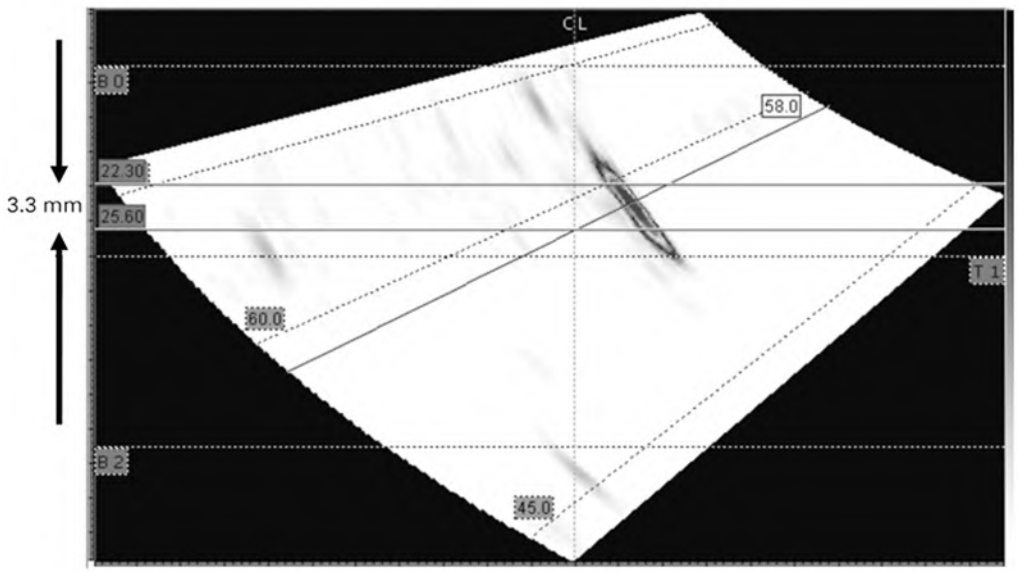
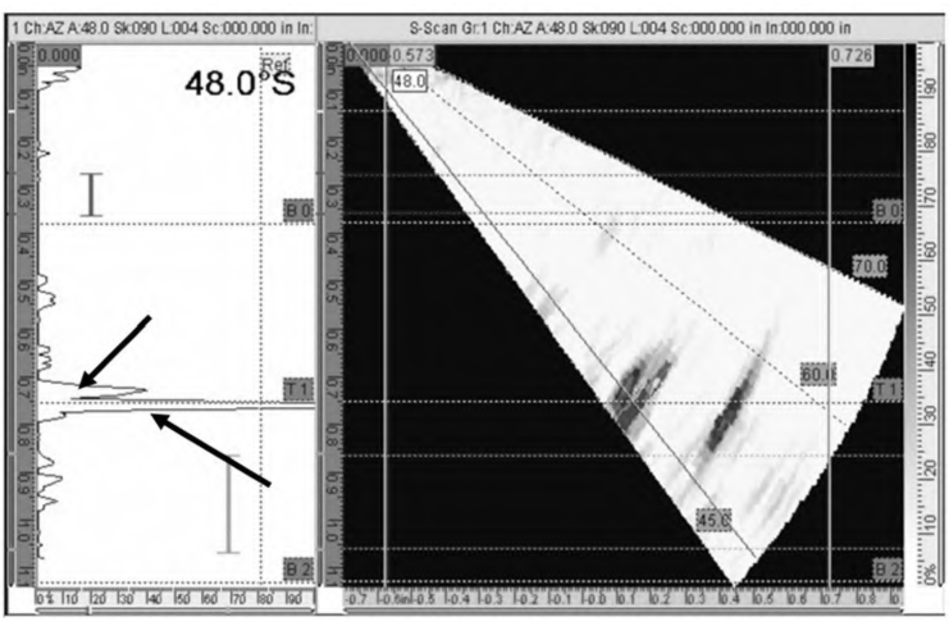


Figure P-452.2-2
Flaw Height Sizing Using Tip Diffraction Technique and the Horizontal Cursors on the S-Scan Display



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

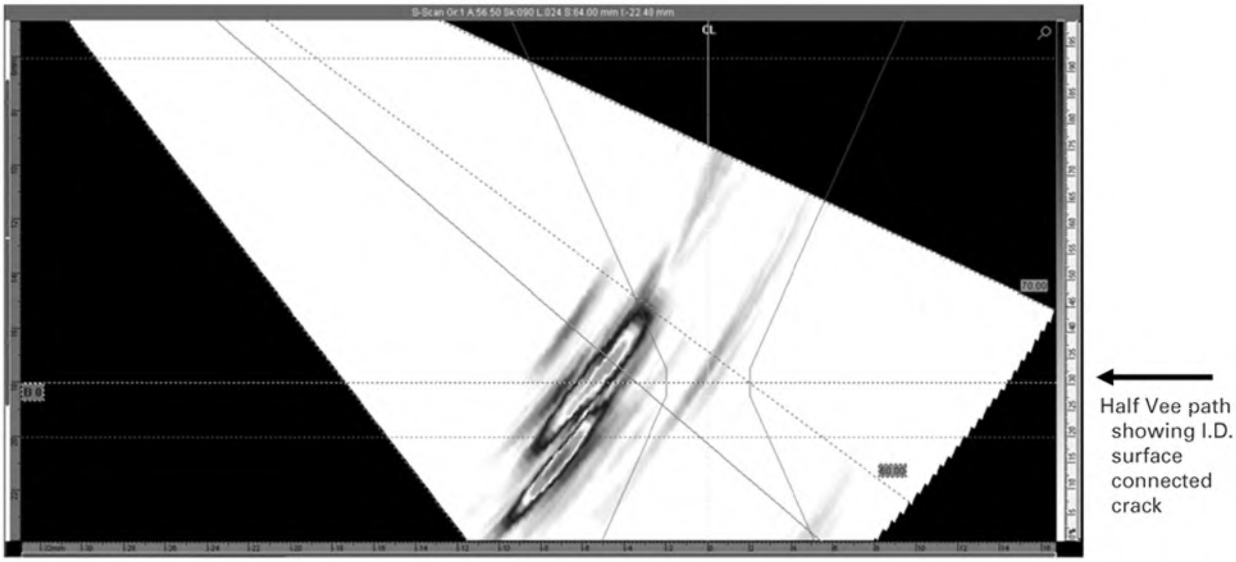


Figure P-481.1
E-Scan of LOF in Midwall

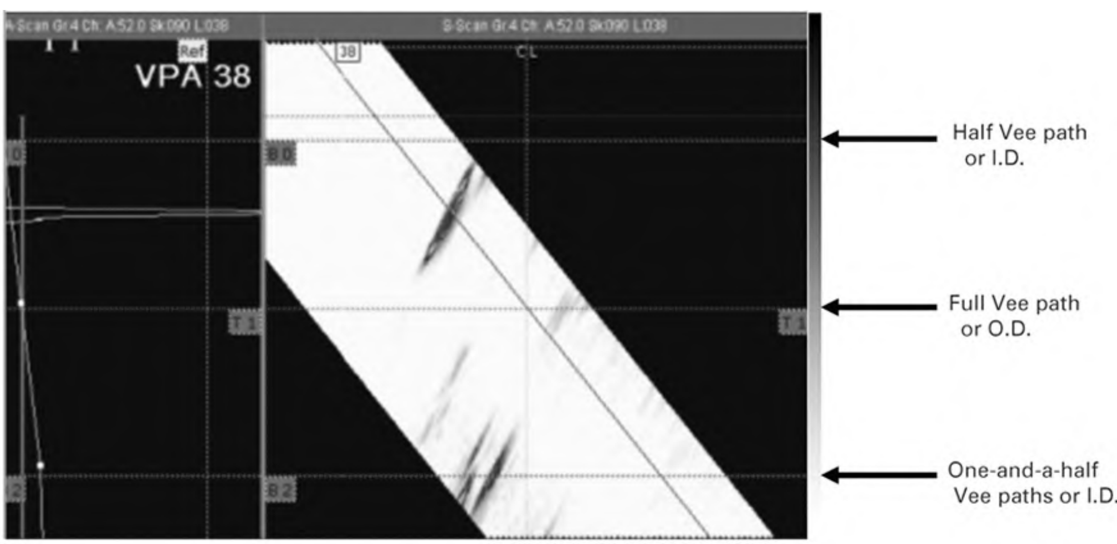


Figure P-481.2
S-Scan of Porosity, Showing Multiple Reflectors

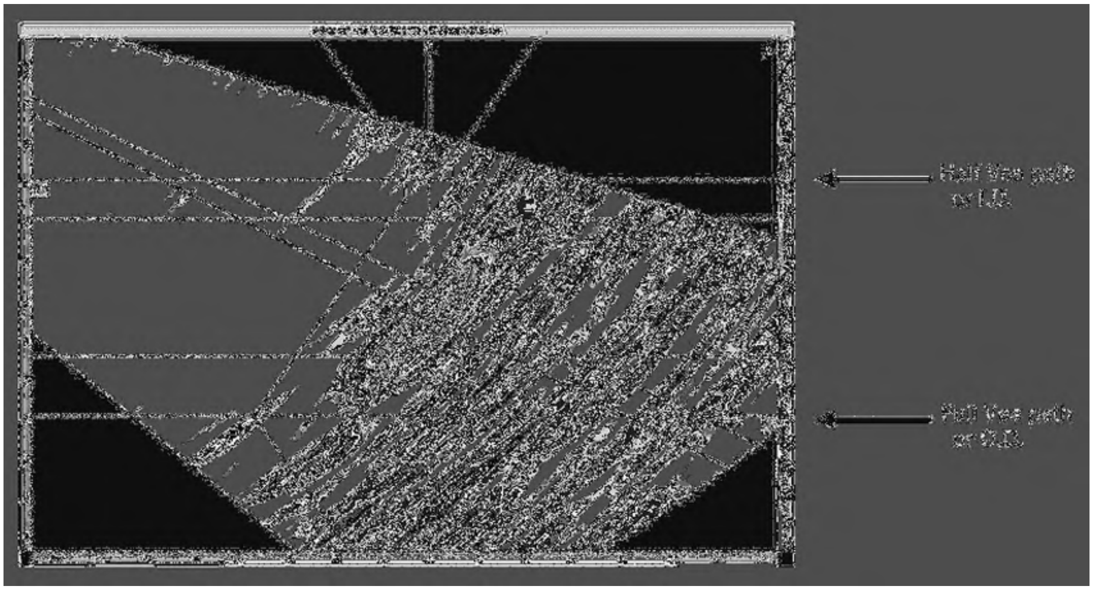


Figure P-481.3
O.D. Toe Crack Detected Using S-Scan

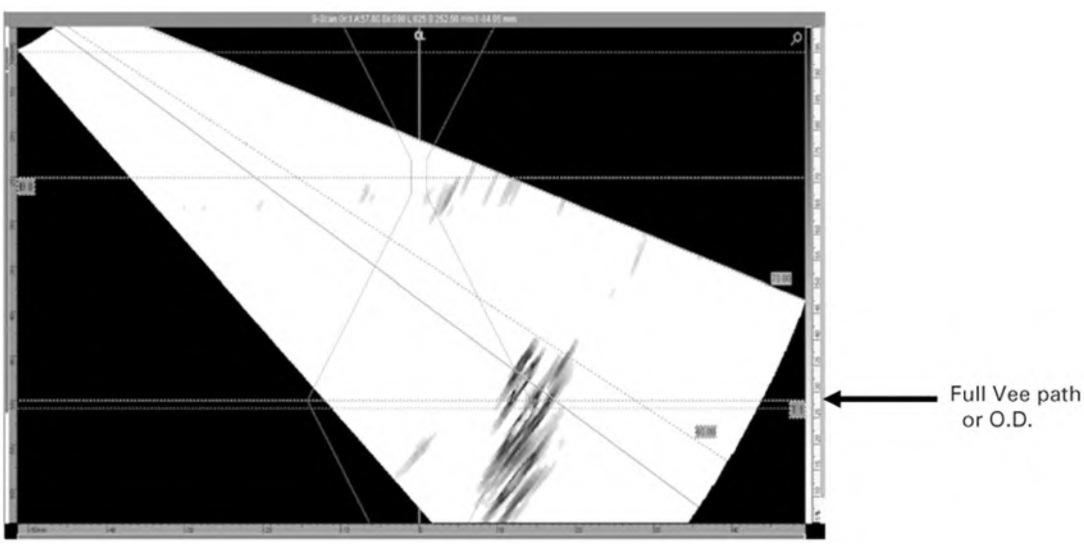


Figure P-481.4
IP Signal on S-Scan, Positioned on Root

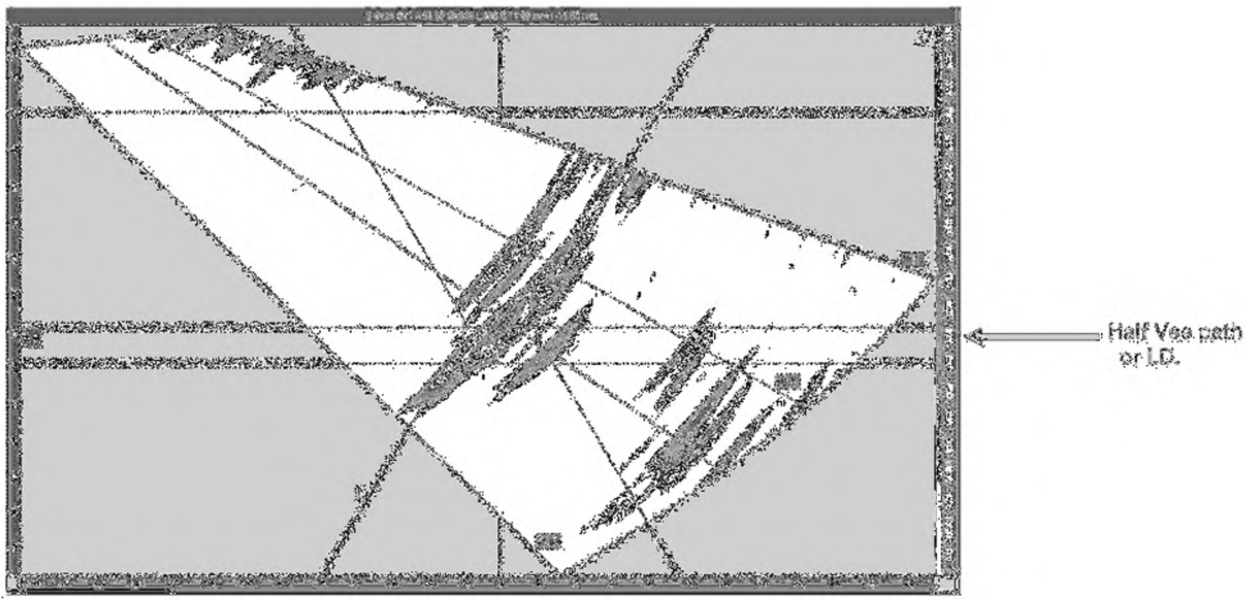
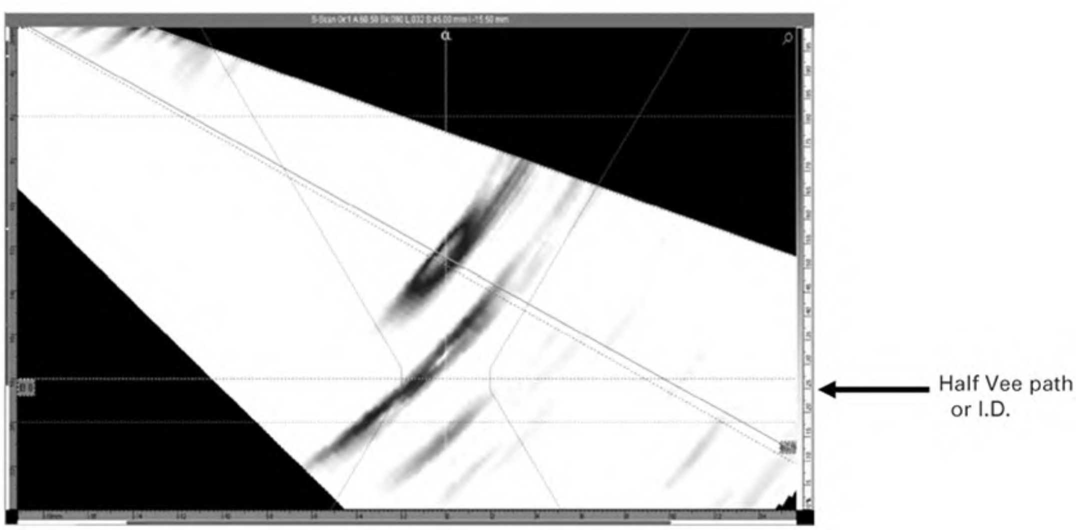


Figure P-481.5
Slag Displayed as a Midwall Defect on S-Scan



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

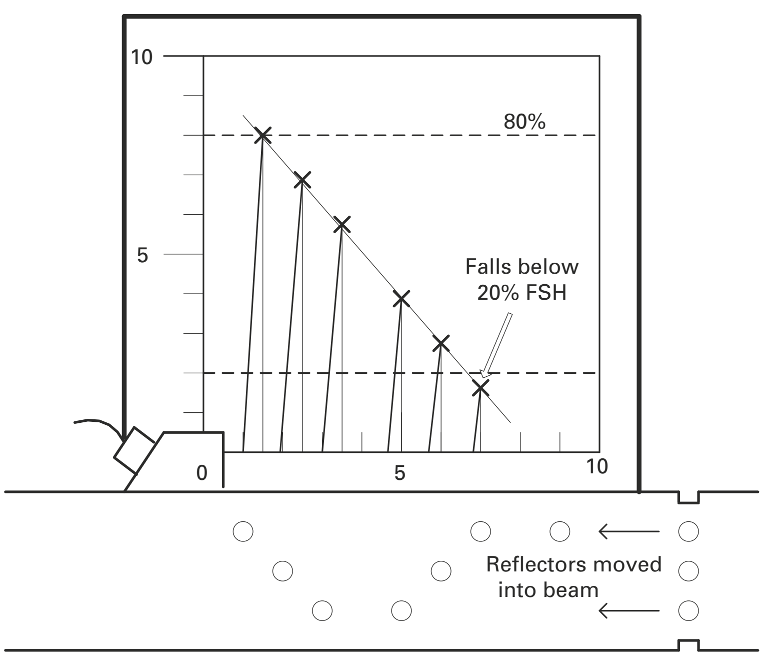


Figure Q-421
First DAC Curve

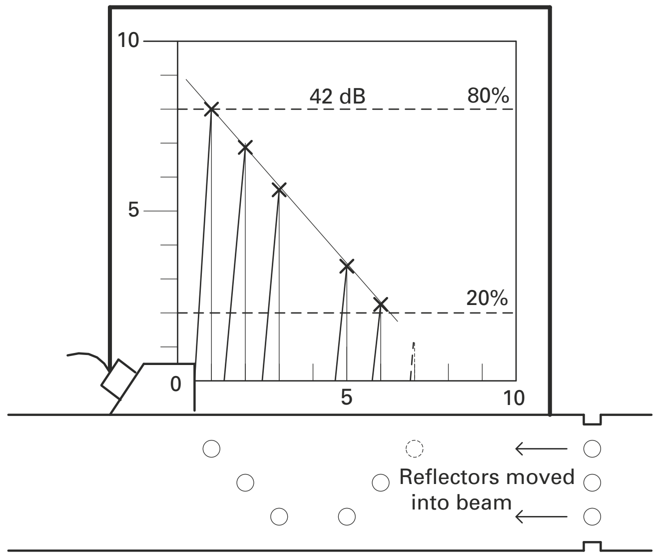
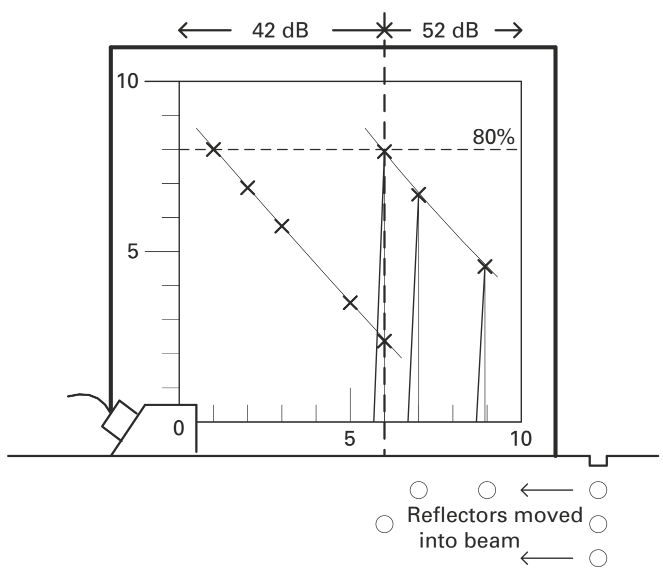


Figure Q-422
Second DAC Curve



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.

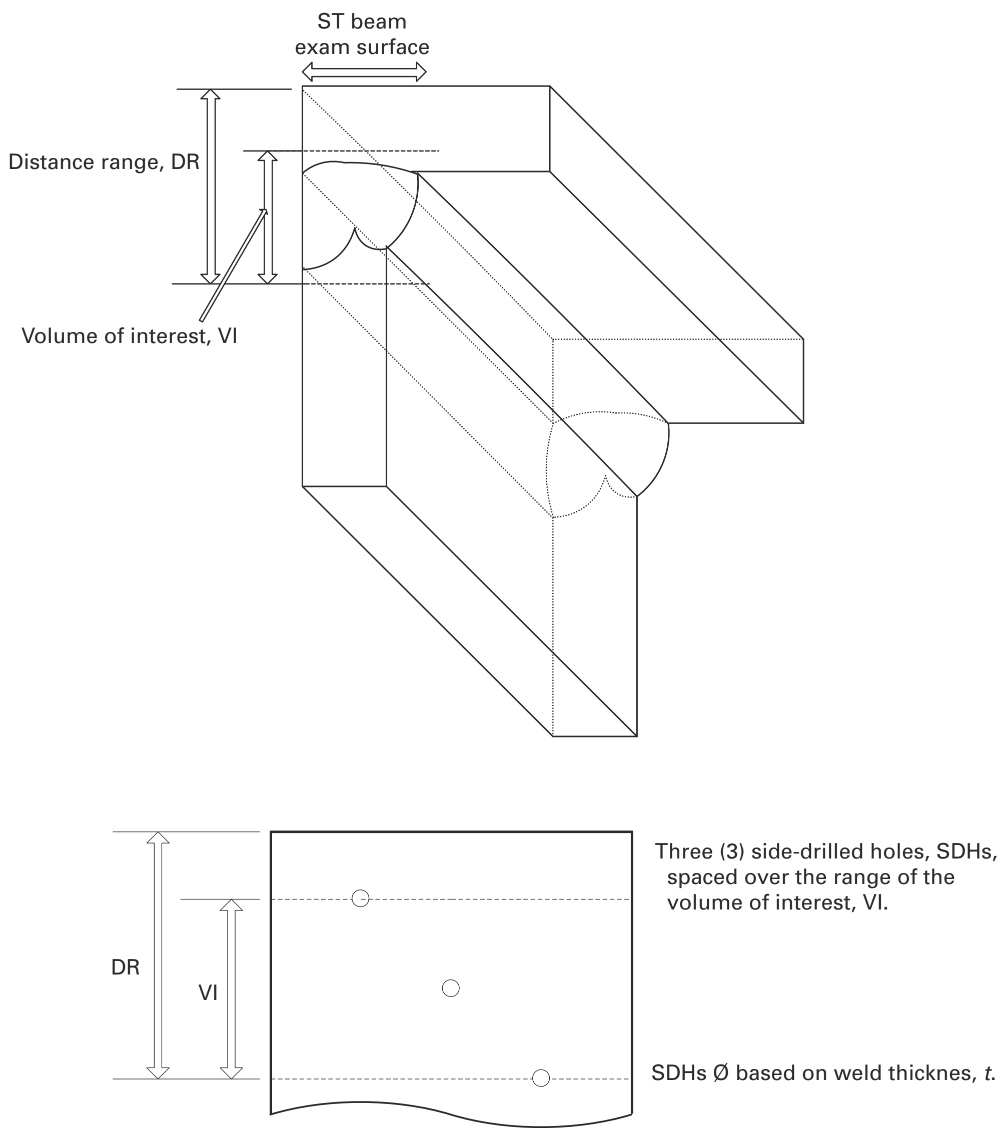
R-430 EQUIPMENT

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

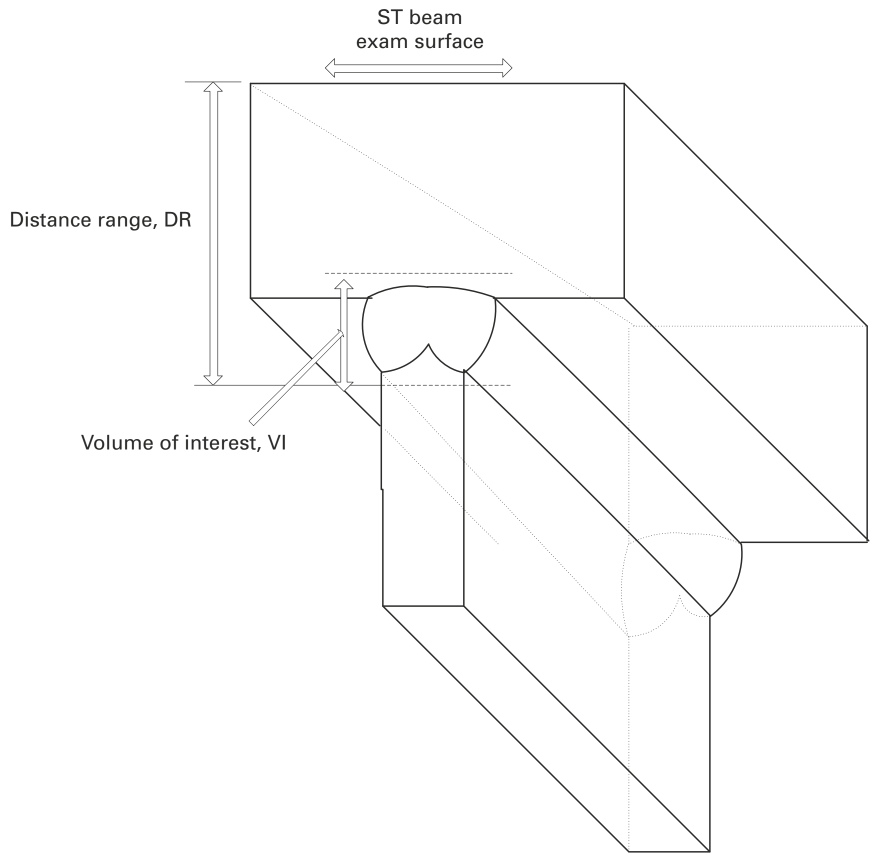


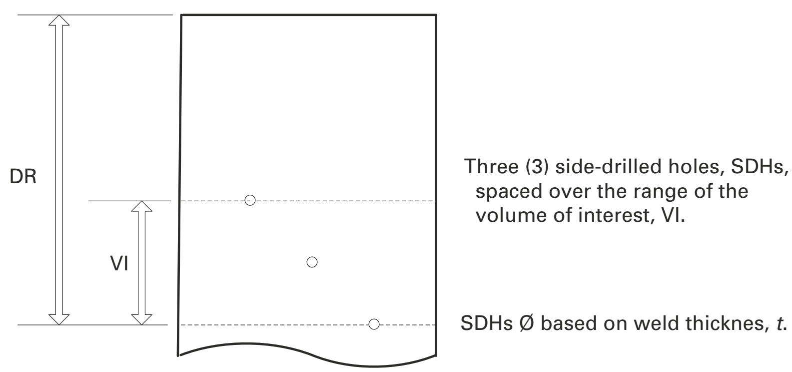
GENERAL NOTES:

(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.

NONMANDATORY APPENDIX S GENERAL TECHNIQUES FOR STRAIGHT-BEAM TRANSFER CORRECTION

S-410 SCOPE

This Appendix provides general techniques for straight-beam transfer correction. This correction is required when variables such as surface finish, heat treatment, and thickness influence the attenuation properties of the material.

S-420 CALIBRATION

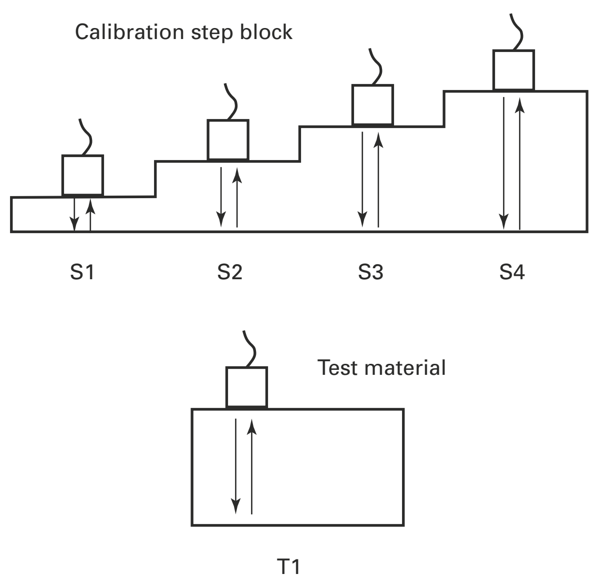
Calibrate the instrument for the examination before performing the transfer correction.

S-430 SIGNAL ADJUSTMENT

Place the search unit on the calibration step block at location S1 and adjust the gain until signal S1 is at 80% to 100% of full screen height (FSH) (see Figure S-430-1). Record or set the gain setting as the reference level.

NOTE: Gain should be set such that the amplitude from the test material signal is not saturated.

Figure S-430-1
Signal Adjustment (Back Wall)



S-440 DISTANCE–AMPLITUDE CORRECTION (DAC)

With the gain setting at the reference level, place the search unit on the calibration block at locations S1, S2, S3, S4, etc., and record or mark the amplitude of each signal (i.e., S1, S2, S3, S4, etc.) (see Figure S-440-1).

Connect the amplitude points of the signals (i.e., S1, S2, S3, S4, etc.) with a smooth line to create a DAC curve.

S-450 TEST MATERIAL ADJUSTMENT

Using the same search unit and reference level setting as in S-430, place the search unit on the material to be tested (T1) (see Figure S-430-1).

Record or mark the amplitude of signal T1 as a percent of the DAC curve (% DAC).

NOTE: On materials where variations of attenuation may exist (e.g., welds), test material adjustment should be performed at various positions through the material.

S-460 CALCULATE THE TRANSFER CORRECTION

Using the following formula, calculate the transfer correction, Δ dB, between the calibration block and the test materials:

$$\Delta \text{ dB} = 20 \log \left(\% \frac{\text{DAC}}{100} \right)$$

(a) Example 1

(1) Given. T1 = 60% DAC (see Figure S-460-1).

(2) Calculation. 20 log (60/100) = −4.4 dB

(3) Conclusion. T1 is 4.4 dB below DAC. Therefore, 4.4 dB is the transfer correction that must be added to the reference level.

(b) Example 2

(1) Given. T1 = 150% DAC (see Figure S-460-2).

(2) Calculation. 20 log (150/100) = 3.5 dB

(3) Conclusion. T1 is 3.5 dB above DAC. Therefore, 3.5 dB is the transfer correction that must be subtracted from the reference level.

NOTES:

(1) This process may be used with a single-thickness calibration block using multiple reflectors.

(2) The Δ dB can be determined by other means (e.g., by manually increasing or decreasing the instrument gain to match the DAC curve and observing the Δ dB).

Figure S-440-1
DAC Curve for Straight-Beam Transfer Correction

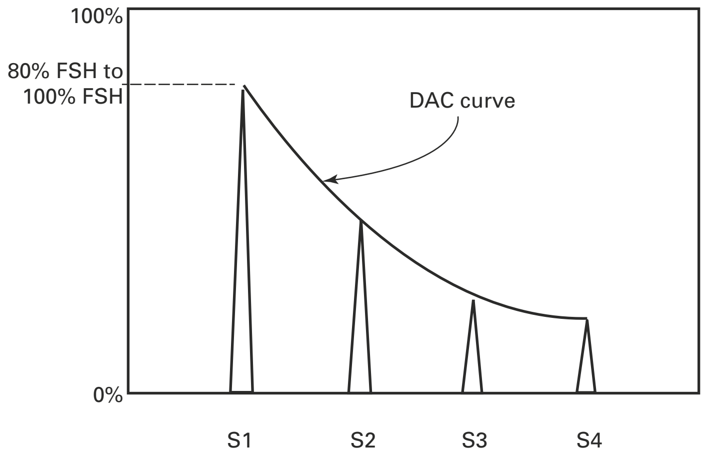


Figure S-460-1
Example 1 (Straight-Beam Transfer Correction)

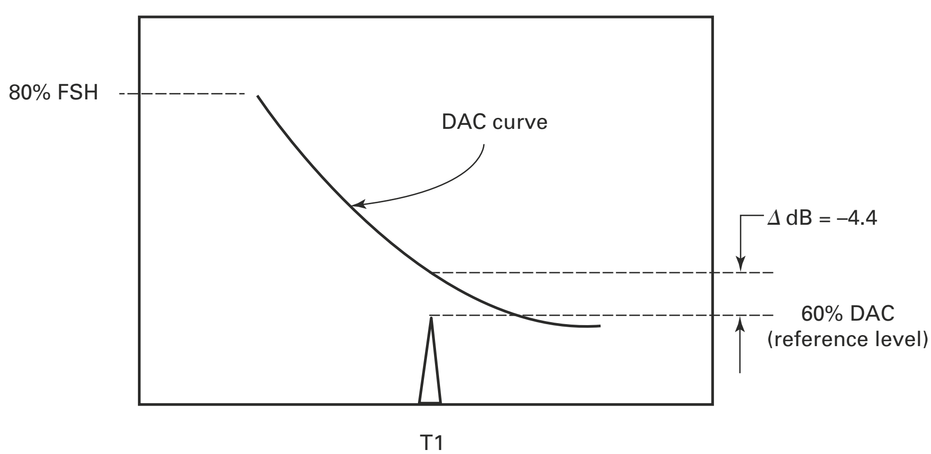
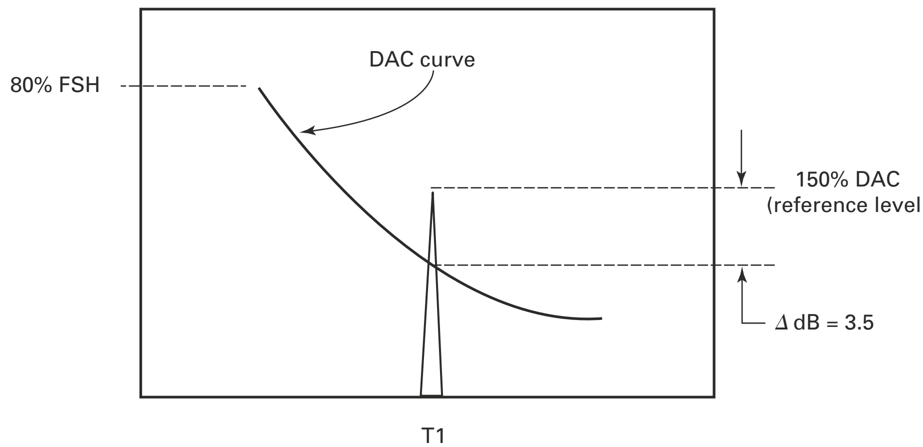


Figure S-460-2
Example 2 (Straight-Beam Transfer Correction)



NONMANDATORY APPENDIX U GENERAL TECHNIQUES FOR ANGLE-BEAM TRANSFER CORRECTION

U-410 SCOPE

This Appendix provides general techniques for angle-beam transfer correction. This correction is required for examination of nonclad materials when variables such as surface finish, heat treatment, and thickness influence the attenuation properties of the material.

Transfer correction for angle-beam examination can be performed with two identical search units in the dual (transmit–receive) configuration.

U-420 CALIBRATION

Calibrate the instrument for the examination before performing the transfer correction.

U-430 SIGNAL ADJUSTMENT

Place the transmitting search unit on the calibration block at location TR and move the receiving search unit until signal R1 is maximized (see Figure U-430-1). Adjust the gain until signal R1 is at 80% to 100% of full screen height (FSH). Record or set the gain setting as the reference level.

NOTE: Gain should be set such that the amplitude from the test material signal is not saturated.

U-440 DISTANCE–AMPLITUDE CORRECTION (DAC)

With the gain setting at the reference level, move the receiving search unit to locations R2, R3, etc., maximizing the signal at each skip (V-path), and record or mark the amplitude of each signal (i.e., R2, R3, etc.) (see Figure U-440-1).

Connect the amplitude points of the signals (i.e., R1, R2, R3, etc.) with a smooth line to create a DAC curve.

U-450 TEST MATERIAL ADJUSTMENT

Using the same search unit and reference level as in U-440, place the search unit on the material to be tested at location TR and move the receiving search unit until signal T1 is maximized (see Figure U-450-1).

Maximize the signal of the skip (V-path) and record or mark the amplitude of signals T1, T2, T3 as a percent of the DAC curve (% DAC). Use the same number of skips in the test material as was used in the calibration block.

NOTE: On materials where variations of attenuation may exist (e.g., welds), test material adjustment should be performed at various positions through the material.

U-460 CALCULATE THE TRANSFER CORRECTION

Using the following formula, calculate the transfer correction, Δ dB, between the calibration block and the test materials:

$$\Delta \text{ dB} = 20 \log\left(\% \frac{\text{DAC}}{100}\right)$$

(a) Example 1

(1) Given. T1 = 70% DAC (see Figure U-460-1).

(2) Calculation. 20 log (70/100) = −3.1 dB

(3) Conclusion. T1 is 3.1 dB below DAC. Therefore, 3.1 dB is the transfer correction that must be added to the reference level.

(b) Example 2

(1) Given. T1 = 140% DAC (see Figure U-460-2).

(2) Calculation. 20 log (140/100) = 2.9 dB

(3) Conclusion. T1 is 2.9 dB above DAC. Therefore, 2.9 dB is the transfer correction that must be subtracted from the reference level.

NOTE: The ΔdB can be determined by other means (e.g., by manually increasing or decreasing the instrument gain to match the DAC curve and observing the ΔdB).

Figure U-430-1
Signal Adjustment (Angle Beam)

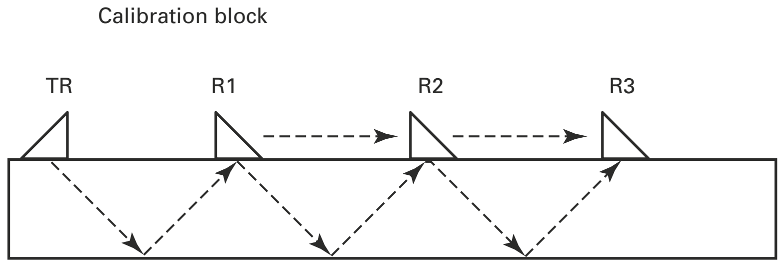


Figure U-440-1
DAC Curve

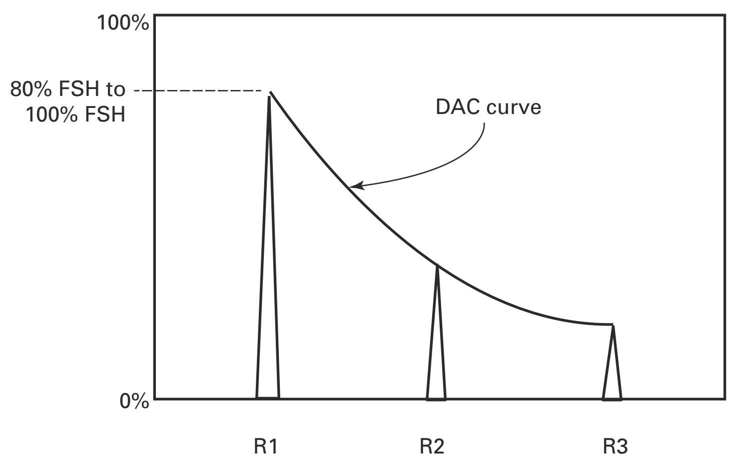


Figure U-450-1
Signal Adjustment (Angle Beam)

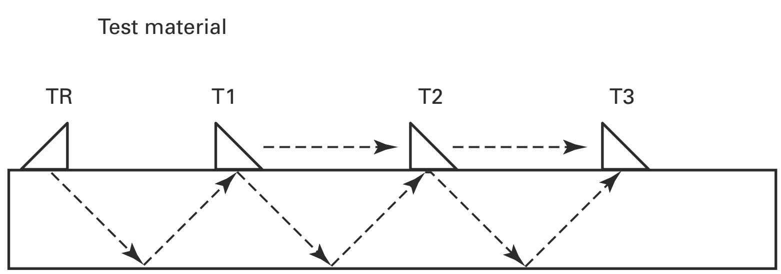


Figure U-460-1
Example 1 (Angle-Beam Transfer Correction)

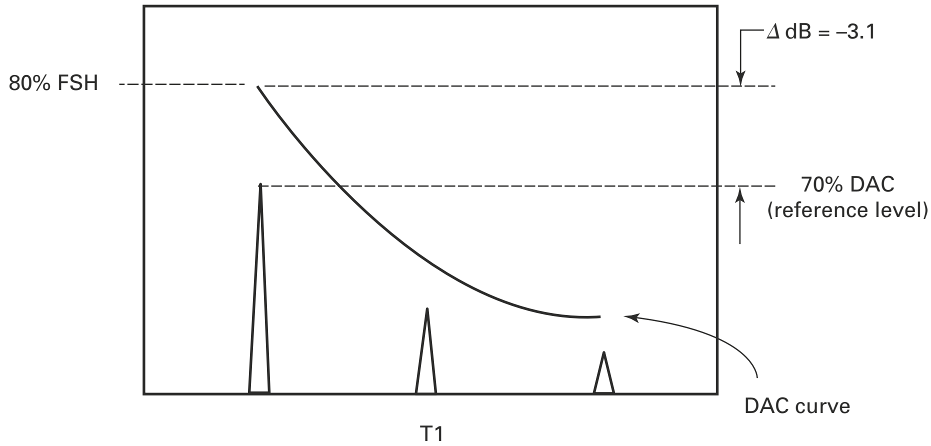
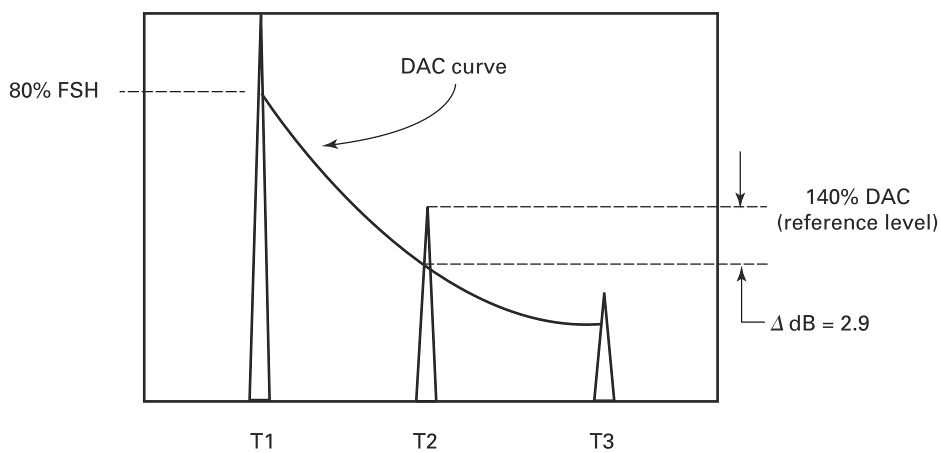


Figure U-460-2
Example 2 (Angle-Beam Transfer Correction)



NONMANDATORY APPENDIX W
PULSE-ECHO METHOD EXAMINATION OF BRAZED JOINTS

W-410 SCOPE

This Appendix provides a pulse-echo method of examination for brazed joints using contact or immersion testing.

W-430 EQUIPMENT

W-431 ULTRASONIC EXAMINATION INSTRUMENT

The ultrasonic examination instrument shall be capable of transmitting, receiving, and displaying high-frequency electrical pulses using search units at frequencies and amplitudes necessary to perform the examination. Sound beams may be collimated, flat, or focused. Suitability shall be determined by using the appropriate reference standard.

W-432 IMMERSION SYSTEM

If used, the immersion system shall be sufficient to permit examination in accordance with T-471.1. A system capable of producing a C-scan of the brazed joint is recommended, unless otherwise specified. If an A-scan is used, an audible electronic defect alarm or a stop-on-defect alarm is recommended.

W-433 COUPLANT

The couplant, including additives, shall not be detrimental to the material being examined.

W-434 REFERENCE STANDARDS

Reference standards shall consist of a brazed joint mock-up consisting of the same base material, brazing filler metal, and fit-up as the joint being examined. The mock-up shall contain natural or artificial discontinuities of known location and size that yield ultrasonic indications above and below the rejection criteria specified in the relevant brazing procedure specification. The reference standard brazed joint shall be at the same distance from and orientation to the front and rear surfaces as brazed joints in the components to be examined. The reference standard also shall have discontinuities of known location and be a suitable size for the calibration of the examination system. To ensure a proper setup, an assembly that is partially brazed around the fitting circumference, as shown in Figure W-434-1, shall be used.

Figure W-434-1
Assembly Partially Brazed Around the Fitting Circumference

GENERAL NOTE: Figure courtesy of Walter J. Sperko, P.E.

W-460 CALIBRATION

W-461 SWEEP RANGE CALIBRATION

W-461.1 Delay Control Adjustment. Position the search unit for the maximum indication of the single wall thickness at the nonbrazed section of the reference standard. Adjust the left edge of this indication to line 2 on the screen with the delay control.

W-461.2 Range Control Adjustment. Position the search unit for the maximum indication of the combined joint thickness at the brazed section of the reference standard. Adjust the left edge of this indication to line 6 on the screen with the range control.

W-461.3 Repeat Adjustments. Repeat the delay and range control adjustments until both thickness indications start at sweep lines 2 and 6.

W-461.4 Sensitivity. The ultrasonic sensitivity shall be demonstrated on a reference standard meeting the requirements of W-434. Scan the rejectable discontinuities on the reference standard to determine which discontinuity produces the lowest amplitude. Adjust the sensitivity (gain) control on this discontinuity to provide an 80% (±5%) of full screen height (FSH) indication. This is the primary reference level. The scanning sensitivity level shall be set a minimum 6 dB higher than the reference level gain setting.

The examiner should be able to show the thickness of the fitting and the tube and, at the brazed or soldered joint, the sum of the fitting thickness plus the tube thickness. The examiner may then scan joints and map out filled and unfilled zones as shown in Figure W-461.4-1.

Figure W-461.4-1
Filled and Unfilled Zones of a Joint

GENERAL NOTE: Figure courtesy of Walter J. Sperko, P.E.

W-470 EXAMINATION

W-471 PREPARATION OF COMPONENT FOR EXAMINATION

The surface of the component to be examined shall have no braze metal, flux residue, or other contaminant that would prevent the proper examination of the joint. The entry surface finish shall allow the transmission of the ultrasonic energy.

W-472 COMPONENT CONFIGURATION

All components shall be of a configuration suitable for examination. The ultrasonic entry surface must be accessible and surface disruptions such as steps, lands, slots, or holes should be minimized to allow proper examination of the joint.

W-473 CONTACT TESTING

The examination shall be conducted in the pulse-echo mode. The ultrasonic beam shall be normal to the examination surface.

W-473.1 Search Unit. The beam angle shall not vary more than 2 deg from perpendicular nor shall the water path length vary more than 0.20 in. (5 mm) from the distance specified. The scanning index increment shall not exceed 0.04 in. (1 mm). The scanning speeds and scanning parameters shall be such that the ultrasonic indications from the discontinuities in the reference standard are clearly discernible without image distortion or blurring.

W-473.2 System. The part and reference standard shall be placed in a water bath or the transducer shall be housed in a squirter that allows the transmission of ultrasound into the part. A typical system shall consist of computerized X-Y motion controllers, a pulsing and receiving transducer that transmits and collects the raw acoustic energy data, and a computer that records pulsing and receiving data. The computer shall be able to plot the X-Y reflected acoustic energy data as a function of position in gray or color levels, which indicate the energy level (amplitude) of the reflected acoustic signals. The controllers and software shall be capable of scanning speeds and resolution that enable discontinuities in the reference standards to be imaged.

W-474 COVERAGE

If the examination area is examined with more than one scan setup, there shall be a means to show overlap of the different areas in either B-scan or C-scan images.

W-480 EVALUATION

W-481 INDICATION EVALUATION

All indications greater than 50% of the primary reference level shall be evaluated. The indications shall be compared to the reference standard's artificial flaws for acceptability. All evaluated indications shall be identified with the appropriate disposition recorded.

W-481.1 Defect Sizing. Indications shall be measured in two directions (width and length). In each direction, the end points shall be determined by obtaining a 50% amplitude decrease of the primary reference level.

W-481.2 Acceptance Criteria. The acceptance criteria shall be as specified by the referencing Code Section, engineering drawing, or the organization having quality responsibility.

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.[17] Calibration blocks in accordance with Figure T-534.3 shall be used for straight beam examination.

T-534.4 Transfer Correction. When the block material is not of the same product form or has not received the same heat treatment as the material being examined, it may be used provided it meets all other block requirements and a transfer correction for acoustical property differences is used. Article 4, Nonmandatory Appendix S and U (as applicable) may be 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 of the following

(a) the corresponding reference reflector (same type and dimensions) in the calibration block and in the component to be examined

(b) two search units positioned in the same orientation on the calibration block and component to be examined

The examination sensitivity shall be adjusted for the difference.

T-560 CALIBRATION

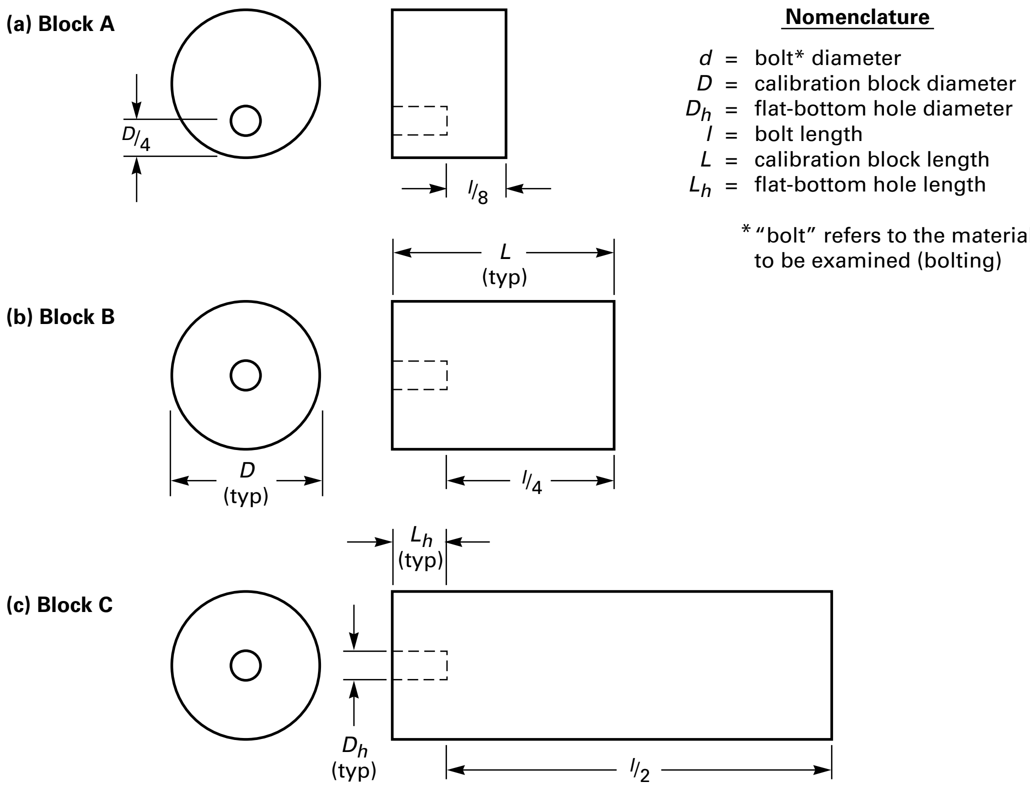
T-561 INSTRUMENT LINEARITY CHECKS

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.

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
≤1 in. (≤25 mm)	$d \pm d/4$	1/16 in. (1.5 mm)
>1 in. (>25 mm) to 2 in. (50 mm)	$d \pm d/4$	1/8 in. (3 mm)
>2 in. (>50 mm) to 3 in. (75 mm)	$d \pm d/4$	3/16 in. (5 mm)
>3 in. (>75 mm) to 4 in. (100 mm)	$d \pm d/4$	5/16 in. (8 mm)
>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 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.

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 (**25**)

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical after evaluation and recording of the indications as stated in T-591, 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.

(25) **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, in. (mm)	Notch Depth [Note (1)]
<2 (<50)	1 thread depth
≥2 but <3 (≥50 but <75)	$^5/_{64}$ in. (2.0 mm)
≥3 (≥75)	$^3/_{32}$ 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 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.

(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.

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

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 techniques:

(a) water washable
(b) post-emulsifying
(c) solvent removable

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.

(25) T-660 CALIBRATION

Visible light meters and UV-A radiometers 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	Welds, heat-affected zones, and castings	Porosity, lack of fusion, cracks (all forms), cold shuts	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.

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.

(25) **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 a UV-A lamp. 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 lamps that operate in the range between 320 nm and 400 nm (3200 Å and 4000 Å).

(d) UV-A lamps 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 shall be clean prior to use. Cracked or broken reflectors, filters, glasses, or lenses shall not be used.

(f) The UV-A intensity shall be measured with a UV-A radiometer prior to use, whenever the lamp'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 (25)

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical after evaluation and recording of the indications as stated in T-691 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) penetrant material manufacturer's name, product designation, and batch number 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.

(25) II-642 AUSTENITIC OR DUPLEX STAINLESS STEEL AND TITANIUM

When examining austenitic or duplex stainless steel and titanium, all penetrant materials, except potable water, shall be analyzed individually for chlorine and fluorine content in accordance with SE-165. The total chlorine and fluorine content shall not exceed 0.1% by weight.

II-643 WATER (25)

(a) Potable water used in precleaning or other processes is not required to be analyzed for chlorine or 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.

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.”

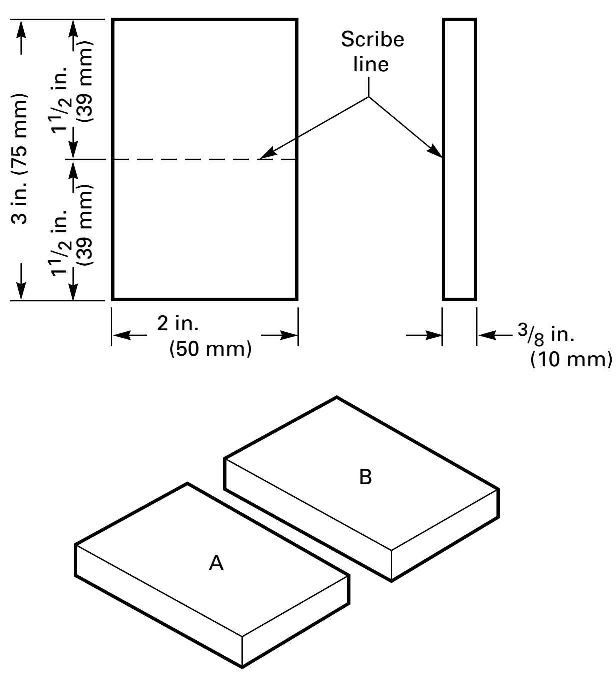
III-640 REQUIREMENTS

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

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

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.

(25)

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 or particles manufacturer's name and product designation, 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