SSC-245

A GUIDE FOR INTERPRETATION OF NONDESTRUCTIVE TESTS OF ORDINARY-, MEDIUM-, AND HIGH-STRENGTH LOW-ALLOY STEEL BUTT-JOINT WELDMENTS IN SHIP HULL STRUCTURES

SHIP STRUCTURE COMMITTEE
1977

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SR-197

In 1966, the Ship Structure Committee published a "Guide for Interpretation of Non-Destructive Tests of Welds in Ship Hull Structures" - SSC-177, that was developed by modifying codes and standards for structures other than ship hulls. In 1970, the Committee published "A Guide for Ultrasonic Testing and Evaluation of Weld Flaws" - SSC-213, that retained the comparable radiographic acceptance limits provided in SSC-177.

With additional service experience and the constant stream of test data on weldments being generated, the Committee requested the above guides be revised and updated to consider this new information while still maintaining the essential integrity of the weld without excessive demands that might adversely influence cost. This report, SSC-245, "Guide for Interpretation of Non-Destructive Tests of Ordinary -, Medium -, and High-Strength, Low-Alloy Steel Weldments in Ship Hull Structures," constitutes the revised and combined guide. Users are cautioned that this guide is not a standard and they should follow the current appropriate regulations, rules, or standards for their particular application.

W. M. Benkert
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

FINAL TECHNICAL REPORT

on

Project SR-197

GUIDE FOR INTERPRETATION OF NONDESTRUCTIVE TESTS OF ORDINARY-, MEDIUM-, AND HIGH-STRENGTH, LOW-ALLOY STEEL WELDMENTS IN SHIP HULL STRUCTURES

Prepared for the

SHIP STRUCTURE COMMITTEE

by the

WELD FLAW EVALUATION COMMITTEE

of the

SHIP RESEARCH COMMITTEE

National Academy of Sciences--National Research Council

U. S. Coast Guard Headquarters
Washington, D.C.
1977

ABSTRACT

A survey was made of various codes and standards applicable to the interpretation of nondestructive tests of welds in *ordinary-, medium-, and high-strength* low-alloy steels. This guide has been developed for application to steel welds in ship hull structures of the general cargo, tanker and passenger class as differentiated from naval ships. The guide exhibits nondestructive test results of several classes of defects with suitable tests to delineate the maximum size and/or distribution that would be recommended as acceptable for ship hulls.

FOREWORD

This Guide has been prepared to provide uniform inspection in shipyards where ordinary-, medium-, and high-strength low-alloy steels are used. It is not intended to replace the standards issued by regulatory or classification authorities but rather to complement them.

The Committee's original purpose was to prepare a guide for inspecting high-strength low-alloy steel weldments. During the development of this effort, it became evident that the resultant guides would apply to all ship-grade steel weldments.

The reader is cautioned, however, that although the guides are similar for all ship-grade steel strengths, more extensive nondestructive testing is recommended as the strength of the steels increase. Likewise, it should also be mentioned that the four principal nondestructive test methods presented herein must be considered as complementary rather than supplementary -- each having advantages and weaknesses with respect to usage and results. This is reflected in the acceptance criteria recommended herein. The selection and application of the method to be used must, therefore, be carefully made by trained personnel familiar with the fabrication of ship hull steels.

W. W. Offner
Chairman,
The Weld Flaw Evaluation Committee

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SCOPE

This document defines suggested acceptance criteria for nondestructive testing of ordinary-, medium-, and high-strength low-alloy (HSLA) steel weldments in plate thicknesses from 1/2 inch through 3 inches as utilized in the construction of hulls of modern merchant surface vessels and supercedes the criteria recommended in SSC-177* and SSC-213**. It is not the object of this document to designate the location or extent of the inspection on a ship's hull, but rather to provide guides for the interpretation of such tests by qualified personnel. It is expected that only those discontinuities need be removed and repaired as necessary to render the weld acceptable in accordance with the applicable guides herein.

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*Weld Flaw Evaluation Committee, Guide for Interpretation of Nondestructive Tests of Welds in Ship Hull Structures, SSC-177, Ship Structure Committee, Washington, D.C. 1966.

**Youshaw, R. A., A Guide for Ultrasonic Testing and Evaluation of Weld Flaws, SSC-213, Ship Structure Committee, Washington, D.C. 1970.

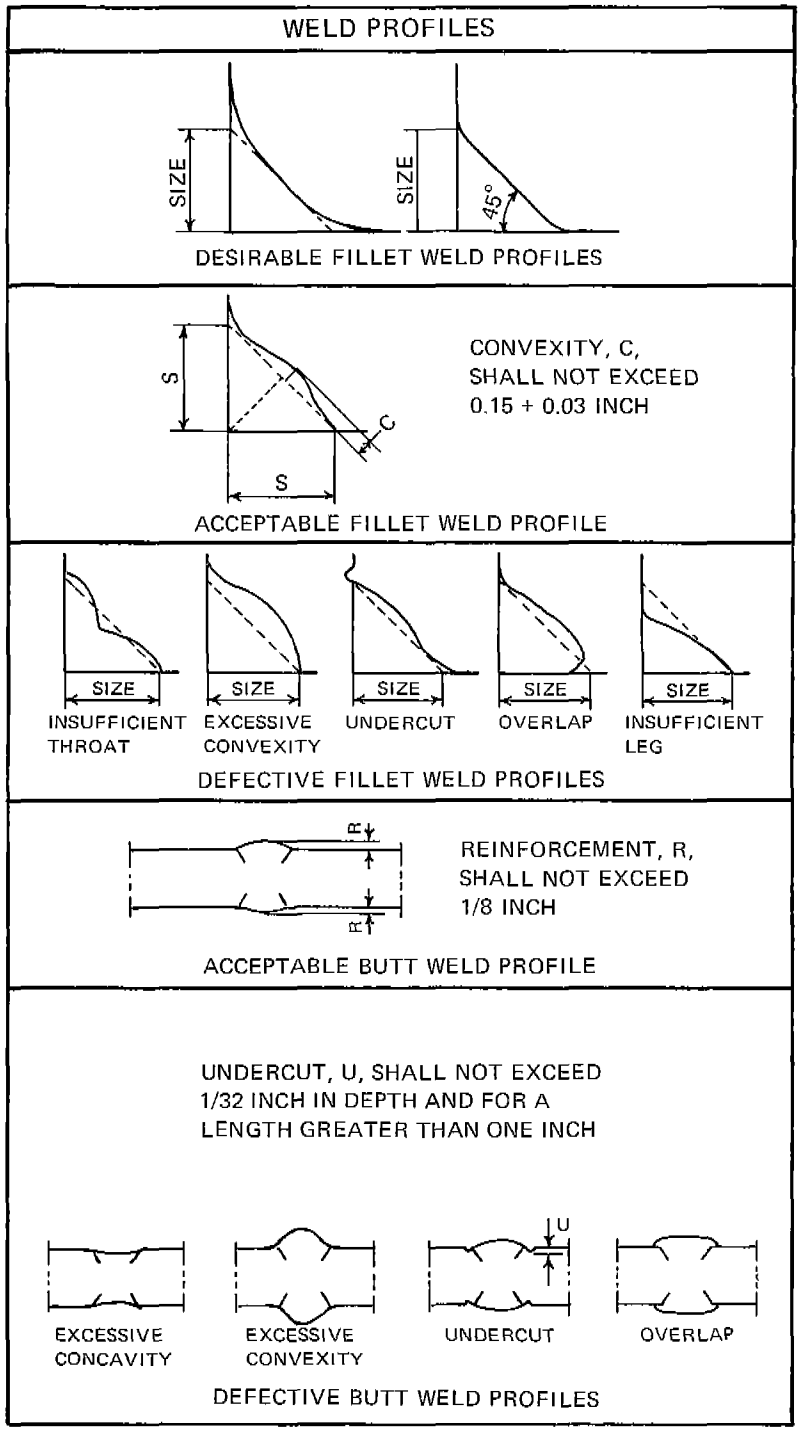


Fig. 1. - Visual Inspection Guides

PERSONNEL QUALIFICATIONS

The American Society for Nondestructive Testing standard SNT-TC-IA, "Nondestructive Test Personnel Qualification and Certification -- Recommended Practice" shall apply to each of the individual inspection categories.

VISUAL

Test Method

The test method as provided on pages 155 through 157 of Welding Inspection, American Welding Society, 1968, should be used.

Interpretation Guides

The following criteria are to be used in the evaluations:

1. Fillet and butt-welds should conform to the requirements shown in Fig. (1) for size, convexity, concavity, undercut, overlap, leg, throat, and excessive weld irregularities.

2. Surface porosity (sometimes called pock-marks) is unacceptable. (Fig. 2)

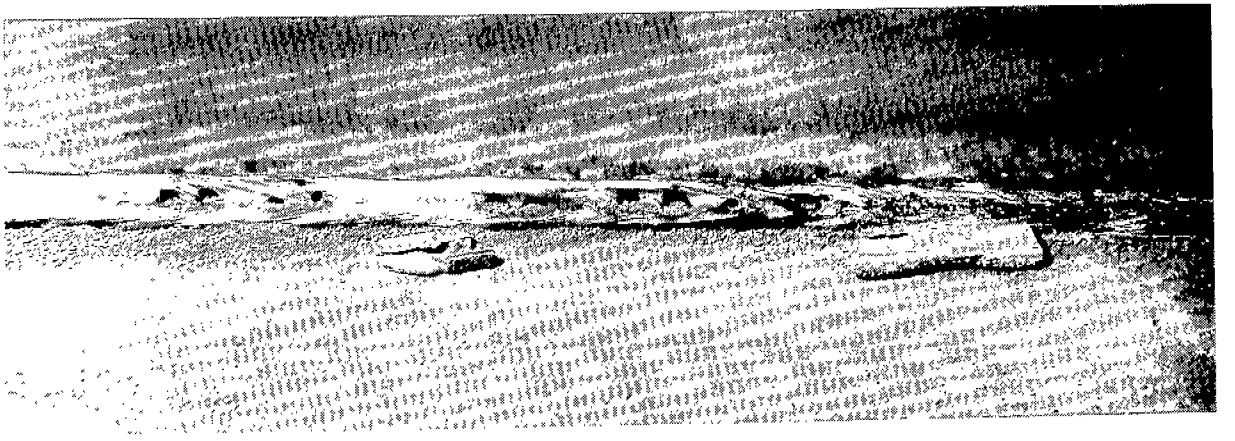


Fig. 2. - Surface Porosity by Visual Inspection

RADIOGRAPHY

Test Method

The guides set forth in this section are applicable to the radiographic inspection of welds in butt joints only. The test method as provided in the American Society for Testing and Materials Standard ASTM E-142-72 should be used. The ASTM E-142-72 standard, without its appendices, is reproduced as Appendix A to this report.

Interpretation Guides

For information, prints of radiographs showing types of weld defects are included. However, for various indications of porosity, the original radiographic film of ASTM Standard E-390-69 should be used for weld interpretation. The following criteria are to be used in the evaluation:

1. Welds which contain cracks are unacceptable. (Fig. 3)

2. Welds which contain piping are unacceptable. (Fig. 4)

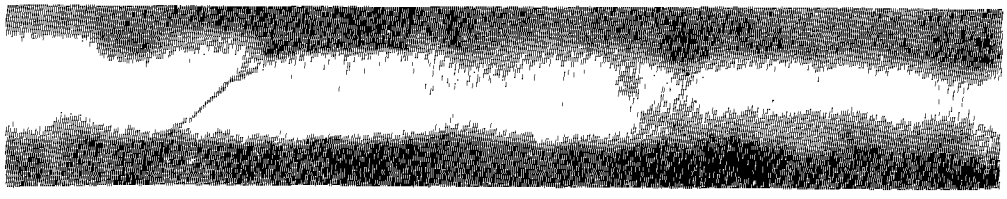


Fig. 3. - Radiographic Print of a Crack

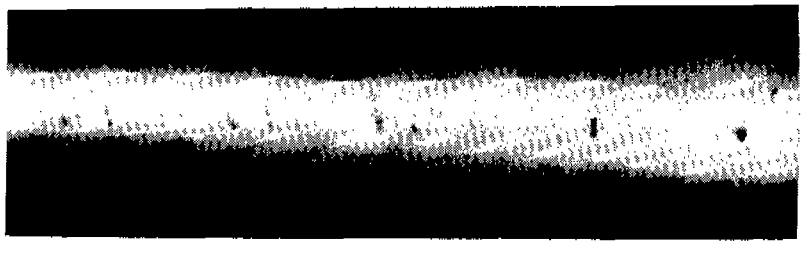


Fig. 4. - Radiographic Print of Piping

3. Welds which contain incomplete penetration (Fig. 5) or lack of fusion (Fig. 6) having individual length in excess of (1/4)T or 3/8-inch, whichever is less, are unacceptable. The total cumulative length of such defects shall not exceed (1)T in any (6)T distance. Additionally, the separation between adjacent defects, along the length of the weld, shall not be less than (1/2)T, where T is the thickness of the inner plate.

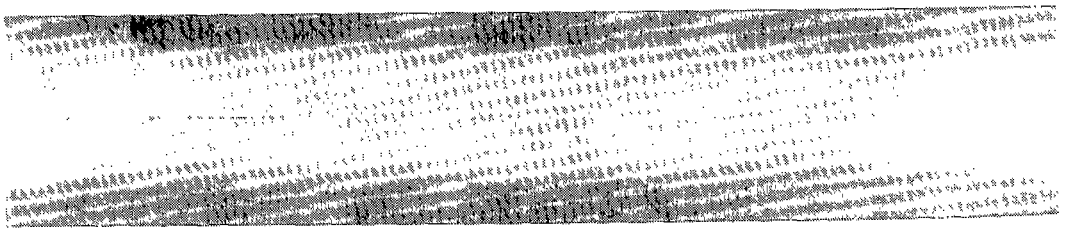


Fig. 5. - Print of Radiograph Illustrating Incomplete Penetration

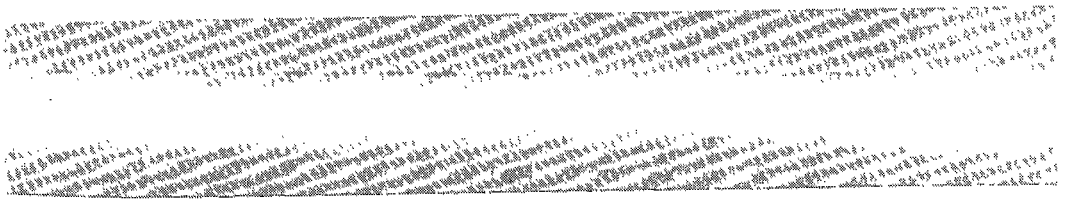


Fig. 6. - Radiographic Print of Lack of Fusion

4. Welds which contain elongated round-edged slag inclusions greater in length than (1/2)T or 3/4-inch, whichever is less and where T is the thickness of the thinner plate, are unacceptable. (Fig. 7)

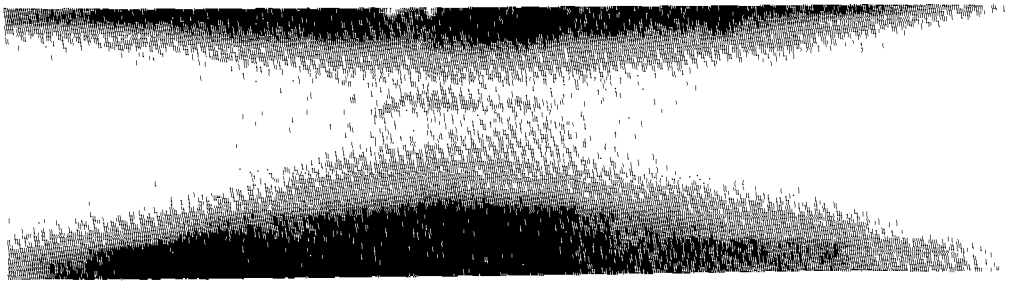


Fig. 7. - Radiographic Print of Elongated Round-Edged Slag Inclusion

5. Welds which contain elongated slag inclusions having crack-like indications are unacceptable. (Fig. 8)

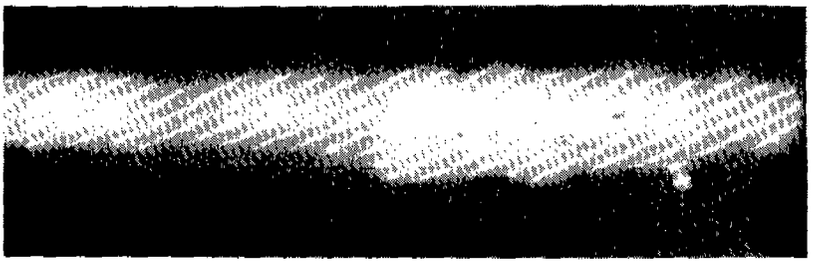


Fig. 8. - Radiographic Print of Crack-Like Slag Inclusion

6. Welds which contain multiple slag inclusions having individual lengths smaller than (1/2)T or 3/4-inch, whichever is less, and where the total cumulative length of such defects exceeds (1)T in any (6)T distance, are unacceptable. In addition, the weld is unacceptable if the separation between adjacent defects, along the length of the weld, is more than (1/2)T, where T is again the thickness of the thinner plate. (Fig. 9)

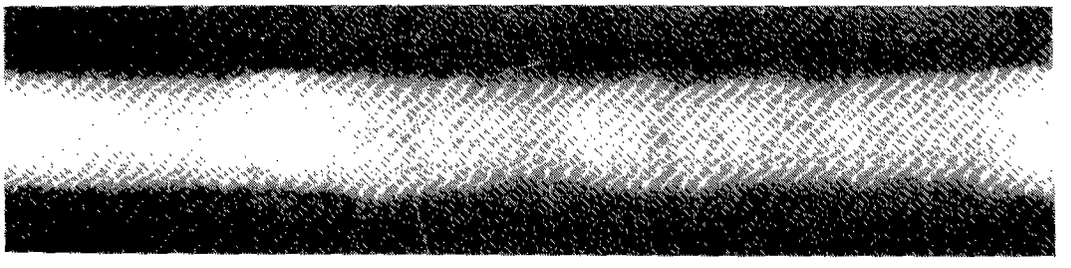


Fig. 9. - Radiographic Print of Multiple Slag Inclusions

. Welds which show a radiographic indication of an undercut (Fig.10) should be judged by using the visual inspection guide.

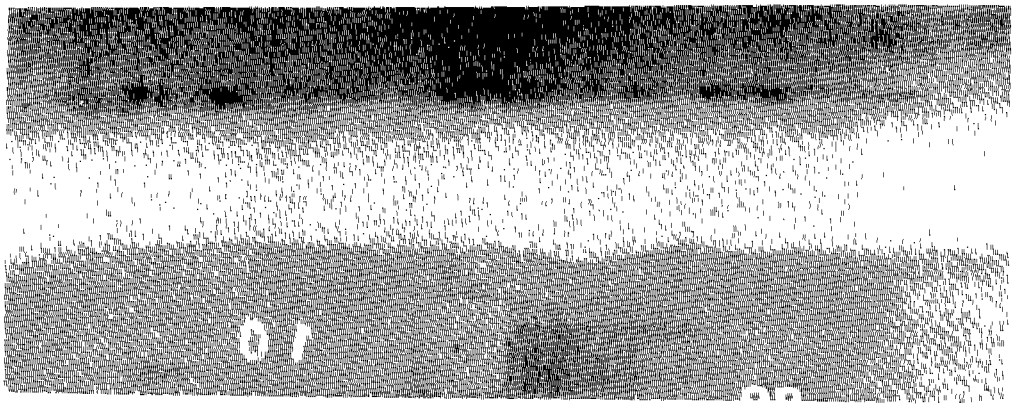


Fig. 10. - Radiographic Print of Undercutting

. Welds in which the radiographs show porosity should be judged unacceptable if they contain porosity equal to or in excess of the limits shown in Figs. 11 and 12 .

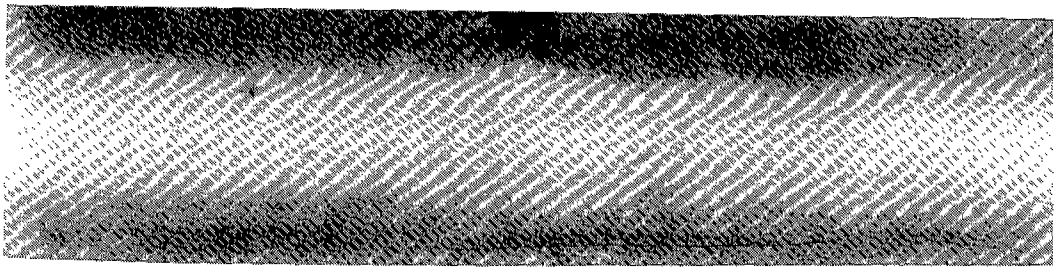


Fig. 11a. Coarse Scattered Porosity (ASTM Grade 2 in 3/4-in. thick plate)

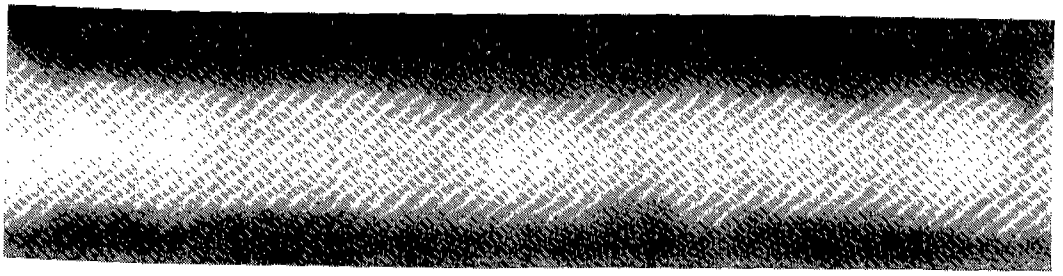


Fig. 11b. Fine Scattered Porosity (ASTM Grade 4 in 3/4-inch thick plate)

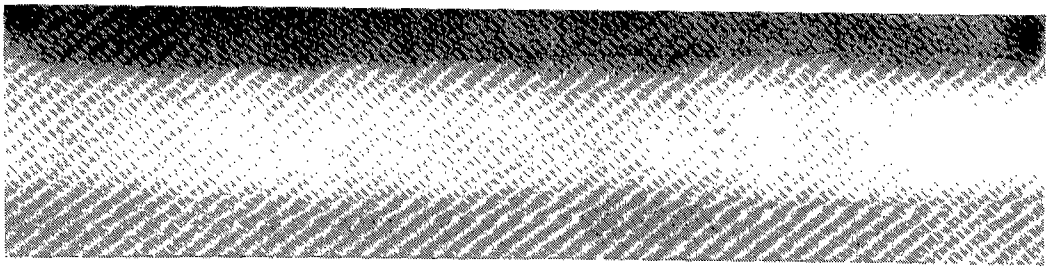


Fig. 11c. Clustered Porosity (ASTM Grade 2 in 3/4-inch thick plate)

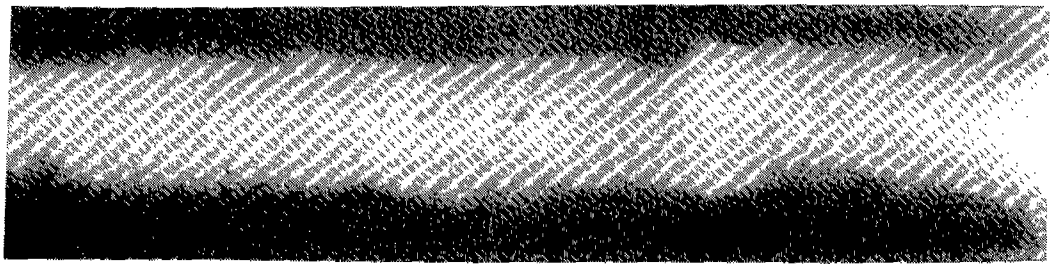


Fig. 11d. Linear Porosity (ASTM Grade 2 in 3/4-inch thick plate)

Fig. 11. - ASTM Prints of Radiographs Illustrating Various Types of Porosity in Plate Thickness from 1/2 inch to 1-1/2 inches

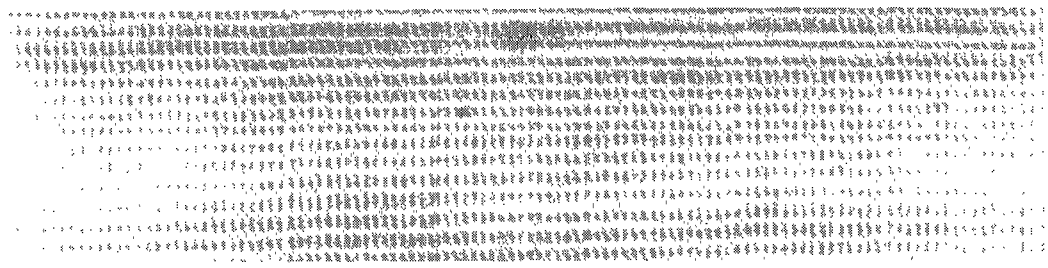


Fig. 12a. Coarse Scattered Porosity (ASTM Grade 3 in 2-inch thick plate)

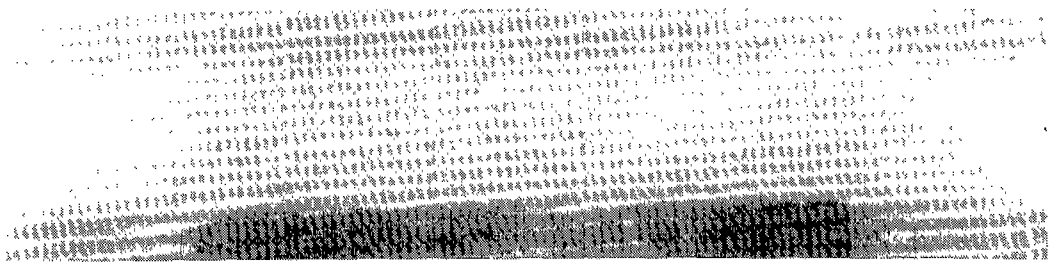


Fig. 12b. Fine Scattered Porosity (ASTM Grade 4 in 2-inch thick plate)

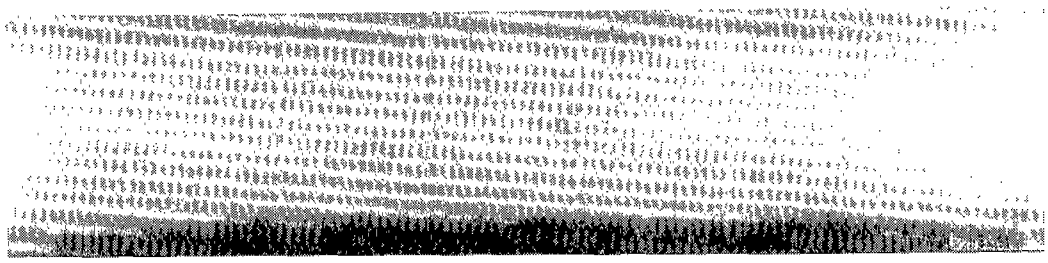


Fig. 12c. Clustered Porosity (ASTM Grade 2 in 2-inch thick plate)

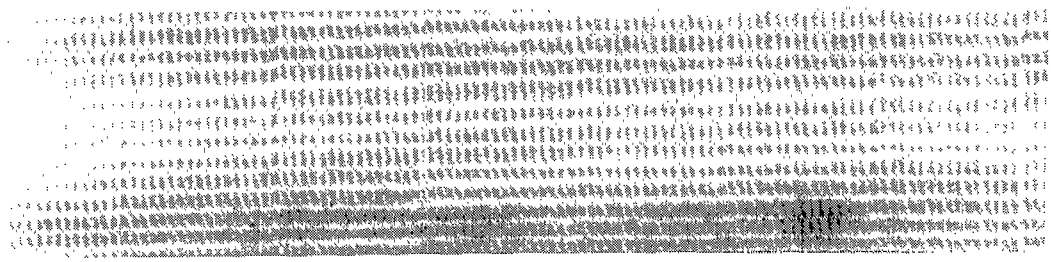


Fig. 12d. Linear Porosity (ASTM Grade 2 in 2-inch thick plate)

Fig. 12 – ASTM Prints of Radiographs Illustrating Various Types of Porosity in Plate Thickness Greater than 1-1/2 inches and up to 3-inches.

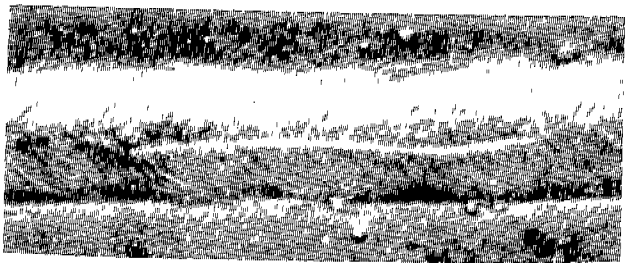


Fig. 13 - Longitudinal Crack Indicated by Magnetic-Particle Inspection.

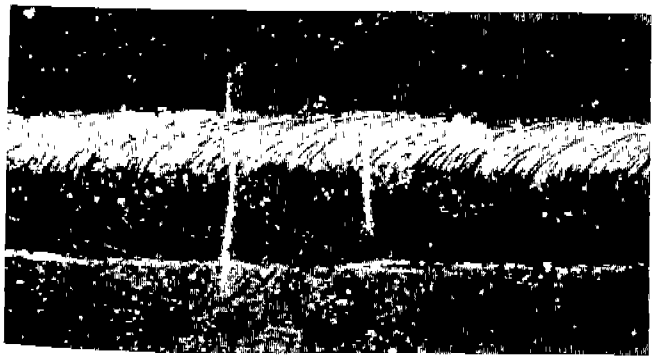


Fig. 14 - Transverse Crack Indicated by Magnetic-Particle Inspection.

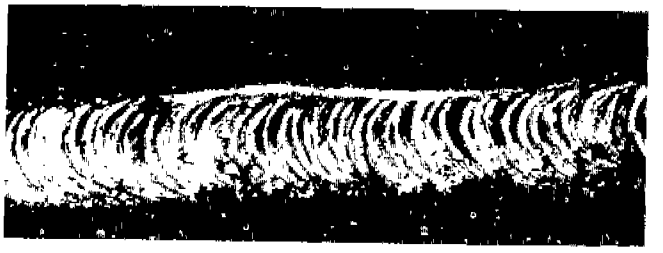


Fig. 15 - Fillet Weld Toe Crack Indicated by Magnetic-Particle Inspection.

Fig. 16 - Root Crack Indicated by Magnetic-Particle Inspection.

MAGNETIC PARTICLE

Test Method

The magnetic particle inspection method is used for detecting surface or near-surface discontinuities in ferromagnetic metals. It is applicable to fillet as well as butt welds. The dry powder test method in ASTM Standard E 109-63 is recommended. The ASTM E-109-63 standard, without its appendices, is reproduced as Appendix B to this report.

When using the process on HSLA materials and weldments, certain factors not normally associated with process use on lower strength materials need to be considered. In the presence of identical magnetic fields, the alloy content of HSLA steels caused them to exhibit magnetic permeability and retentivity markedly different from that exhibited by lower-strength materials. In conducting magnetic particle tests, particularly where HSLA materials are joined to lower strength steels, the difference in permeability may give rise to indications which are almost impossible to distinguish from flaw indications. These "false indications" can be particularly troublesome at the toes of fillet welds joining HSLA steels, and can result in needless expensive repairs unless properly identified. Light exploratory grinding followed by re-inspection will isolate the true flaw from the "false indication".

Random arc strikes caused by the test prods on HSLA materials, particularly on the higher strength quenched and tempered grades, should be prevented because of high hardenability and resultant crack initiation potential.

Weldments in some quenched and tempered (Q & T) HSLA materials which have been proven crack free during and immediately following welding can nevertheless still develop rejectable defects later. For this reason final magnetic particle inspection of such Q & T HSLA weldments should be delayed for a period of at least seven days.

Interpretation Standards

All weld surfaces containing cracks, porosity and lack of fusion are unacceptable; undercuts should be judged by using the visual inspection guides. Some false indications may occur as a result of fillet weld root conditions or other subsurface discontinuity and these indications should not be considered cause for rejection without further investigation. Typical magnetic-particle indications are shown in Figures (13--17).

Fig. 17 - Slag or Porosity Indicated by Magnetic-Particle Inspection.

LIQUID PENETRANT

Test Method

The liquid penetrant test method as developed in ASTM Standard E-165-65 should be used for detecting the presence of discontinuities open to the surface. Dye penetrant of the water washable type is recommended. The ASTM E-165-65 standard is reproduced as Appendix C to this report.

Interpretation Standard

All weld surfaces containing cracks, porosity and lack of fusion are unacceptable; undercuts should be judged by using the visual inspection guides. Typical liquid penetrant indications are shown in Figures (18-21).

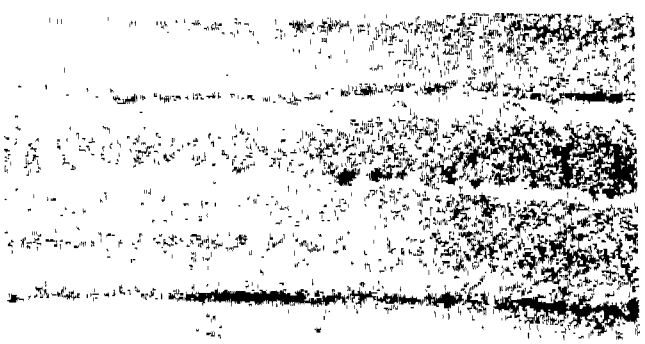


Fig. 18 - Interbead and Marginal Indications (Undercuts) by Liquid Penetration Inspection.

Fig. 19 - Surface Porosity and Undercutting Indications by Liquid Penetrant Inspection.

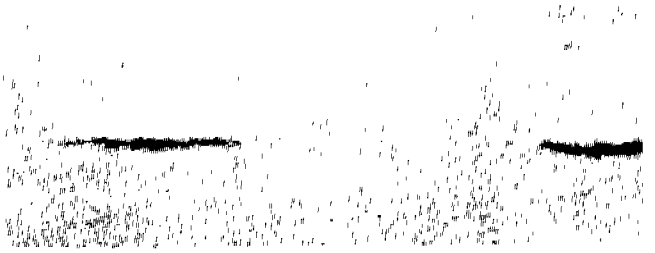


Fig. 20 - Deep Crack Indications by Liquid Penetrant Inspection.

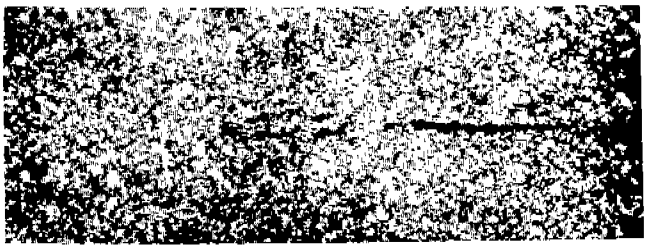
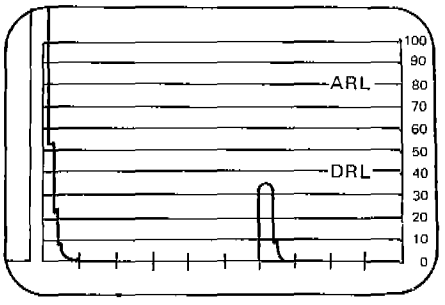
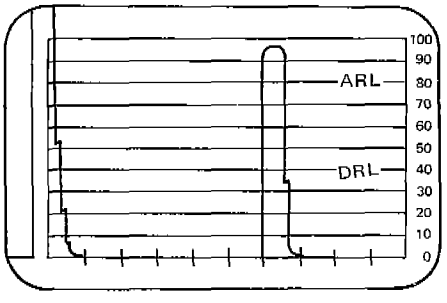


Fig. 21 - Crack and Slag Indications by Liquid Penetrant Inspection.



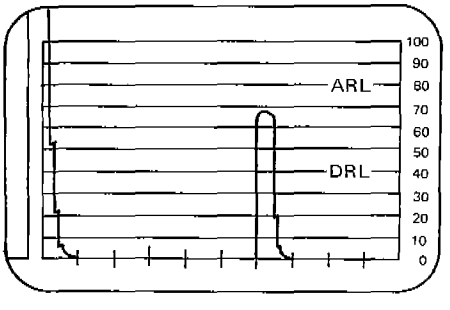
INDICATIONS BELOW THE DRL LEVEL ARE TO BE DISREGARDED

Fig. 22 - Typical Example of Ultrasonic Indication below the DRL (Disregard Level).



INDICATIONS GREATER THAN THE ARL LEVEL ARE REJECTABLE

Fig. 23 - Typical Example of Ultrasonic Indication above the ARL (Amplitude Reject Level).



OTHER INDICATIONS EQUAL TO OR GREATER THAN THE DRL LEVEL REQUIRE A DETERMINATION OF DEFECT LENGTH AND SEPARATION DISTANCE

Fig. 24 - Typical Example of Ultrasonic Indication above the DRL but less than the ARL.

ULTRASONIC

Test Method

The contact ultrasonic inspection of butt welds described in Appendix D is recommended.

Interpretation Standards

When base metals of different thicknesses are welded together, the thickness of the thinner member shall be used in determinations of acceptable limits of discontinuities.

Discontinuities which produce signal amplitudes less than the Disregard Level (DRL), (Fig. 22), are acceptable.

Discontinuities which produce signal amplitudes greater than the Amplitude Reject Level (ARL), (Fig. 23), are unacceptable.

Other discontinuities which cause signal amplitudes equal to or greater than the DRL, (Fig. 24), require a length determination and are evaluated as follows:

a. Discontinuities identified as cracks are unacceptable.

b. Other discontinuties with lengths greater than (1/4)T or 3/8 inch, whichever is less, where T is the thickness of the thinner plate, are unacceptable. Discontinuties identifiable as round-edged slag not greater than (1/2)T of 3/4-inch, whichever is less and where T is the thickness of the thinner plate, are acceptable.

c. Total cumulative discontinuities shall not exceed (1)T in any (6)T distance.

d. Separation between adjacent discontinuities along the length of the weld shall not be less than (1/2)T.

Designation: E 142 – 72

American National Standard Z166.7 1973
Approved June 26, 1973
By American National Standards Institute

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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If not listed in the current combined Index, will appear in the next edition

APPENDIX A

Standard Method for CONTROLLING QUALITY OF RADIOGRAPHIC TESTING[1]

This Standard is issued under the fixed designation E 142; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This method has been approved by the Department of Defense as part of Federal Test Method Standard No. 151b and for listing in the DoD Index of Specifications and Standards. Future proposed revisions should be coordinated with the Federal Government through the Army Materials and Mechanics Research Center, Watertown, Mass. 02172.

[ε] NOTE 1—Figure 1 was editorially corrected in December 1972.
NOTE 2—Footnote 6, in Appendix A2, was added editorially in March 1974.

1. Scope

1.1 This method covers the radiographic testing of materials for internal discontinuities, and also the use of film and other recording media. Requirements expressed in this method are intended to control the reliability or quality of the radiographic images, and are not intended for controlling the acceptability or quality of materials or products.

1.2 The number of areas or parts to be radiographed and the acceptance standard to be applied shall be specified in the contract, purchase order, product specification, or drawings. The quality level required for radiography shall be at least 2 percent (2-2T), unless a higher or lower quality is agreed upon by the purchaser and the supplier.

NOTE 1—Reference should be made to the following publications for pertinent information:
ASTM Recommended Practices E 94, for Radiographic Testing.[2]
O'Connor D. T., and Criscuolo, E. L., "The Quality of Radiographic Inspection," *ASTM Bulletin*, ASTBA, No. 213, April 1956, pp. 53-59.
Safe Handling of Radioactive Isotopes, *Handbook No. 42*, Nat. Bureau of Standards.
X-ray Protection, *Handbook No. 60*, Nat. Bureau of Standards.
Protection Against Radiation from Radium, Cobalt-60, and Cesium-137; *Handbook No. 54*, Nat. Bureau of Standards.

NOTE 2—The values stated in U.S. customary units are to be regarded as the standard.

2. Definitions

2.1 *radiographic inspection*—the use of X rays or nuclear radiation or both, to detect discontinuities in material, and to present their images on a recording medium.

2.2 *recording medium*—a film or detector which converts radiation into a visible image.

2.3 *radiograph*—a permanent visible image on a recording medium produced by penetrating radiation passing through the material being tested.

2.4 *penetrameter*—a device employed to obtain evidence on a radiograph that the technique used was satisfactory. It is not intended for use in judging the size of discontinuities nor for establishing acceptance limits for materials or products.

2.5 *source*—a machine or radioactive material which emits penetrating radiation.

2.6 *source-film distance*—the distance between the radiation producing area of the source and the film.

3. Direction of Radiation

3.1 When not otherwise specified, the direction of the central beam of radiation shall be perpendicular, wherever possible, to the surface of the film.

4. Penetrameters

4.1 The quality of all levels of radiographic testing shall be determined by a penetrameter conforming to the following requirements:

4.1.1 Penetrameters shall be fabricated of radiographically similar material to the object being inspected.

NOTE 3—Radiographically similar material re-

[1] This method is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing.
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[2] *Annual Book of ASTM Standards*, Part 31

fers to materials or alloys which have approximately the same radiation absorption as the material being radiographed. The identical alloy, by chemical analysis, is not usually required.

4.1.2 Penetrameters shall be made in accordance with Fig. 1, except as specified in 4.1.3. Variations in the length and width of rectanguar penetrameters are permitted.

4.1.3 Penetrameter designs other than those in Fig. 1 may be permitted upon contractual agreement provided that the applicable thickness and hole sizes conform to Fig. 1. Other penetrameter requirements shall be adhered to as specified herein.

4.1.4 *Identification*—The rectangular penetrameter shall be identified with a number made of lead which is attached to the penetrameter. The number shall indicate the thickness of the penetrameter in thousandths of an inch. The penetrameter thickness must be selected to indicate the proper quality level, (Table 1).

4.1.5 Penetrameters that otherwise conform to the requirements of this method but do not have the proper identification may be used provided that lead numbers indicating penetrameter thickness are placed adjacent to the penetrameter plaque.

4.1.6 Lead numbers shall be placed adjacent to the circular penetrameters to provide identification of the penetrameter on the film (Table 1).

5. Levels of Inspection

5.1 The quality level required for radiography shall be at least 2 percent (2-2T), unless a higher or lower quality is agreed upon by the purchaser and the supplier. Three quality levels of inspection levels 2-1T, 2-2T, and 2-4T (Note 4), are available through the design and application of the penetrameter as shown in Table 2. Other levels of inspection are available as indicated in Table 3. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1T, 1-1T, and 1-2T by first determining that these quality levels can be maintained in production radiography.

NOTE 4—The first number of the quality level designation refers to penetrameter thickness expressed as a percentage of specimen thickness; the second number refers to the diameter of the penetrameter hole which must be revealed, expressed as a multiple of penetrameter thickness, *T*.

5.2 In specifying radiographic quality levels, the contract, purchase order, product specification, or drawing should clearly indicate the thickness of metal to which the quality level refers. Careful consideration of required radiographic quality levels is particularly important in the examination of double-walled products such as piping or ducts. The thickness of penetrameters employed shall be based upon the thickness of the specimen between the penetrameters and the film holder, including the thickness of penetrameter shims which may be required (see 6.2).

5.3 ASME Boiler and Pressure Vessel Code and other penetrameters will be acceptable under this method provided the hole sizes and penetrameter thickness conform to the requirements specified herein. Modification of ASME penetrameters may be accomplished by drilling a 1T hole adjacent to the existing 2T or 3T holes.

6. Placement of Penetrameters

6.1 Penetrameters shall be placed on the source side of the section being examined and should be placed so that the plane of the penetrameter is normal to the radiation beam. If this is not practicable, placement of the penetrameter on a block is acceptable provided the block is of radiographically similar material, the same thickness as the part being radiographed, and is placed as close as possible to the material being inspected.

6.2 When radiographing welds, penetrameters shall be placed on the parent metal, approximately $^1/_8$ in. (3.18 mm) from the edge of the weld. When weld reinforcement or protruding backing ring is not removed, a shim of the same type of metal as the parent metal shall be placed under the penetrameter to provide the same thickness of material under the penetrameter as the average thickness through the weld. Shims shall exceed the penetrameter dimensions by at least $^1/_8$ in. on all sides and the shimmed penetrameter shall be placed so as not to overlap the backing strip or ring.

6.3 When examining double-walled parts such as piping or duct, with a radiation source outside the pipe, the penetrameter shall be

placed, where practicable, on the outside of the pipe alongside the weld nearest the source of radiation.

6.4 In cases where placement of the penetrameter on the source side is impracticable, the penetrameter may be placed on the film side if one of the following conditions is met:

6.4.1 The radiographic technique shall be demonstrated with the applicable penetrameter placed on the source side and a continuous series of penetrameters placed on the film side of a like pipe section. The series of penetrameters shall range in thickness from 2 percent to 0.5 percent of the material thickness. If the penetrameter on the source side indicates the required sensitivity, the image of the smallest penetrameter hole visible on the film side shall be used to determine the penetrameter and penetrameter hole which shall be used on inspection radiographs.

6.4.2 When radiographing welds in which only the portion of the weld next to the film is viewed, the radiographic technique shall be demonstrated on a similar pipe section with the applicable penetrameters placed on the inside along the root of the weld, and a series of penetrameters, chosen as in 6.4.1, placed on the film side. If the penetrameter on the source side indicates the required sensitivity, the image of the smallest penetrameter hole visible on the film side shall be used to determine the penetrameter and penetrameter holes which shall be used on inspection radiographs

6.5 In the inspection of irregular objects, the penetrameter shall be placed on the part of the object farthest from the film.

7. Number of Penetrameters

7.1 One penetrameter shall represent an area within which radiographic densities do not vary more than −15 or +30 percent (Note 5). At least one penetrameter per radiograph, exposed simultaneously with the specimen, shall be used except as noted in 7.1.1 and 7.1.2 (Note 6).

7.1.1 When film density varies more than −15 or +30 percent from that adjacent to the penetrameter, two penetrameters used in the following manner will be satisfactory. If one penetrameter shows an acceptable sensitivity at the most dense portion of the radiograph and the second penetrameter, placed in accordance with Section 6, shows an acceptable sensitivity at the least dense portion of the radiograph, these two penetrameters will serve to qualify the radiograph.

7.1.2 *Simultaneous Exposures*—When a part or parts of the same design are exposed simultaneously under the same geometrical conditions in a 360-deg radiation beam, a minimum of one penetrameter shall be required in each quadrant.

NOTE 5—Radiographic densities may be measured by a visual comparison technique of known accuracy, such as calibrated film strips. When films are exposed simultaneously in one film holder, density variations should be determined on the single or superimposed films, referred to the manner in which they are interpreted.

NOTE 6—For parts of irregular geometry or widely varying thickness, it may be necessary to radiograph the first unit of a given design to determine proper placement of penetrameters for subsequent radiography.

8. Location of Markers

8.1 The image of the location markers for the coordination of the part with the film shall appear on the film, without interfering with the interpretation, with such an arrangement that it is evident that complete coverage was obtained. These marker positions shall be marked on the part, and the position of the markers shall be maintained on the part during radiography.

9. Identification of Radiograph

9.1 A system of positive identification of the film shall be provided. Any or all of the following may appear: the name of the inspecting laboratory, the date, the part number, the view, and whether original or subsequent exposure.

10. Multiple Film Techniques

10.1 Film techniques with two or more films of equal or different speeds in the same holder will be permitted provided that the appropriate hole in the penetrameter for a specific area is demonstrated.

11. Non-Film Techniques

11.1 The use of non-film imaging techniques will be permitted provided that the applicable penetrameter hole is demonstrated in the resultant image.

12. Image Quality

12.1 The radiographic image shall be free of blemishes which interfere with its interpretation.

13. Source-Film Distance

13.1 Any source-film distance will be satisfactory provided that the required quality level is attained.

14. Records

14.1 Complete records of the technique details shall be maintained by the inspecting laboratory.

15. Safety

15.1 Radiographic procedure shall be carried out under protected conditions so that the radiographer will not receive a maximum whole body radiation dosage exceeding that permitted by city, state, or national codes. The recommendations of the National Committee on Radiation Protection published by the National Bureau of Standards should be the guide to radiological safety.

TABLE 1 Examples of Penetrameter Identification

Identification No. on Penetrameter	Penetrameter Thickness, in. (mm)		Minimum Specimen Thickness, in. (mm)					
			Level 2-1T, 2-2T, and 2-4T		Level 1-1T and 1-2T		Level 4-2T	
5	0.005	(0.127)	1/4	(3.18)	1/2	(12.7)	1/8	(3.18)
6	0.006	(0.152)	5/16	(7.94)	3/4	(15.9)	.	.
8	0.008	(0.203)	1/8	(9.53)	1/4	(19.1)	7/16	(4.76)
9	0.009	(0.229)	7/16	(11.11)	7/8	(22.2)	.	.
10	0.010	(0.254)	1/2	(12.7)	1	(25.4)	1/4	(6.35)
11	0.011	(0.279)	9/16	(14.3)	1 1/8	(28.6)	...	...
12	0.012	(0.305)	5/8	(15.9)	1 1/4	(31.8)	...	..
20	0.020	(0.508)	1	(25.4)	2	(50.8)	1/2	(12.7)
100	0.100	(2.540)	5	(127)	10	(254)	2 1/2	(63.5)
150	0.150	(3.810)	7 1/2	(191)	15	(381)	3 1/4	(95.2)

TABLE 2 Quality Levels of Inspection

Level of Inspection[a]	Penetrameter Thickness	Minimum Perceptible Hole Diameter	Equivalent Penetrameter Sensitivity, percent[b]
2-1T	1/50 (2 percent) of specimen thickness	1T	1.4
2-2T		2T	2.0
2-4T		4T[c]	2.8

[a] *Level 2-1T Radiography*—In level 2-1T radiography the 1T hole in a penetrameter, 1/50 (2 percent) of the specimen thickness shall be visible.

Level 2-2T Radiography—In level 2-2T radiography the 2T hole in a penetrameter, 1/50 (2 percent) of the specimen thickness shall be visible.

Level 2-4T Radiography—In level 2-4T radiography the 4T hole in a penetrameter, 1/50 (2 percent) of the specimen thickness shall be visible.

Special Levels of Inspection—Special levels of inspection are available as shown in Table 3.

[b] Equivalent penetrameter sensitivity is that thickness of penetrameter, expressed as a percentage of the part thickness, in which a 2T hole would be visible under the same radiographic conditions.

[c] For the appropriate thicknesses the outline of the circular penetrameter shall be shown when the 4T hole is specified

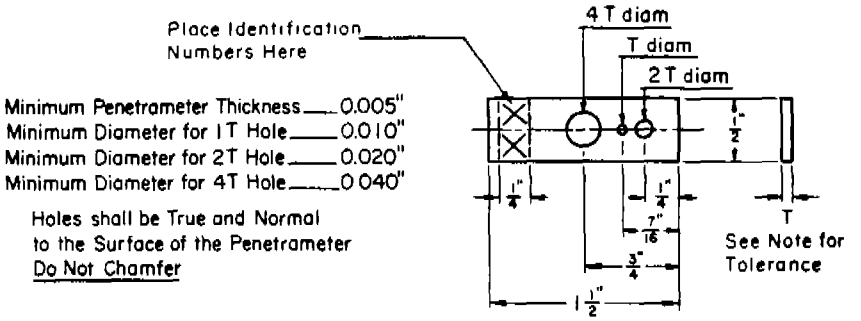
TABLE 3 Special Levels of Inspection

Level of Inspection[a]	Penetrameter Thickness	Minimum Perceptible Hole Diameter	Equivalent Penetrameter Sensitivity, percent[b]
1-1T	1/100 (1 percent) of specimen thickness	1T	0.7
1-2T		2T	1
4-2T	1/25 (4 percent) of specimen thickness	2T	4

[a] *Level 1-1T Radiography*—In Level 1-1T radiography the 1T hole in a penetrameter, 1/100 (1 percent) of the specimen thickness shall be visible.

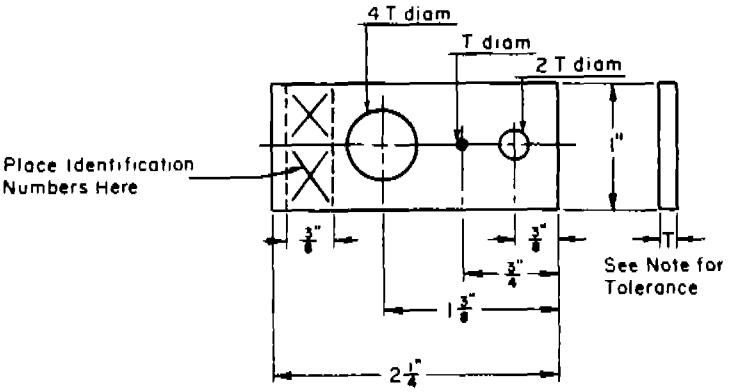
Level 1-2T Radiography—In Level 1-2T radiography the 2T hole in a penetrameter, 1/100 (1 percent) of the specimen thickness shall be visible

Level 4-2T Radiography—In Level 4-2T radiography the 2T hole in a penetrameter, 1/25 (4 percent) of the specimen thickness shall be visible.

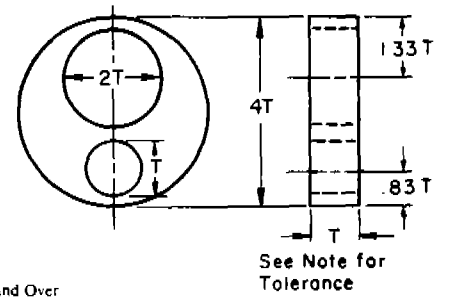


Design for Penetrameter Thickness from 0.005 in. and including 0.050 in.
From 0.005 in. through 0.012. in. see Table I
From 0.012 in. through 0 020 in. Made in 0 0025 in. Increments
From 0.020 in. through 0.050 in Made in 0.005 in. increments

Penetrameter thicknesses between the increments indicated are permitted, provided they do not exceed the maximum thickness required



Design for Penetrameter Thickness from 0.060 in. to and Including 0.160 in.
Made in 0.010 in. Increments.



Design for Penetrameter Thickness of 0 180 in and Over
Made in 0.020 in Increments

NOTE 1—Tolerances on penetrameter thickness and hole diameter shall be ±10 percent or one half of the thickness increment between penetrameter sizes, whichever is smaller.
NOTE 2—1 in. = 25 4 mm.

FIG. 1 Penetrameter Designs.

Designation: E 109 - 63 (Reapproved 1971)

APPENDIX B

American National Standard Z166 1-1973 (R-1969)
Approved Jan 18, 1973
By American National Standards Institute

AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Standard Method for DRY POWDER MAGNETIC PARTICLE INSPECTION[1]

This Standard is issued under the fixed designation E 109; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This method has been approved by the Department of Defense as part of Federal Test Method Standard No. 151b and for listing in the DoD Index of Specifications and Standards. Future proposed revisions should be coordinated with the Federal Government through the Army Materials and Mechanics Research Center, Watertown, Mass 02172.

1. Scope

1.1 This method provides a uniform procedure for magnetic particle inspection with dry powder of large parts such as castings and weldments, that will produce satisfactory and consistent results upon which acceptance standards may be used.

1.2 The procedure outlined in the body of this method provides for local circular magnetization by the use of prod-type contacts. This technique will provide satisfactory inspection of most parts intended for general industrial use where the dry powder method is applicable. There are many applications, however, where the prod technique is either not satisfactory or not the most practical method. Other dry powder methods are outlined in Appendix A1, which should be considered and be used when specified or specifically agreed upon. Neither the method nor the Appendixes include the wet method of magnetic particle inspection, which should be considered where applicable.

1.3 This method does not indicate or suggest standards for evaluation of the indications obtained. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there must be a separate specification or a specific agreement between those responsible for the inspection and the purchasers or users, to accurately define the type, location, and direction of indications considered acceptable, and those considered unacceptable, and those where rework or repair is permitted.

1.4 The dry powder method is more sensitive than the wet method in the detection of near surface discontinuities, but is not as sensitive in detecting fine surface discontinuities. It is also convenient to use in conjunction with portable equipment for the inspection of large areas or for field inspection. It is therefore often used for the inspection of large parts, such as large castings, forgings, or weldments, or parts with rough surfaces. It is not normally used for the inspection of smaller parts such as automotive or aircraft parts where the wet method with stationary equipment is usually more convenient and effective.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

2. Magnetic Particle Inspection

2.1 Magnetic particle inspection is a nondestructive method for detecting cracks and other discontinuities at or near the surface in ferromagnetic materials. Finely divided magnetic particles are applied to the surface of a part which has been suitably magnetized. The particles are attracted to regions of magnetic nonuniformity associated with defects and discontinuities, thus producing indications which are observed visually. This method deals with magnetic particle inspection, using dry powder particles as the inspection medium.

3. Apparatus

3.1 Inspection by the dry method is carried

[1] This method is under the jurisdiction of the ASTM Committee E-7 on Nondestructive Testing.

Current edition effective Sept. 30, 1963. Originally issued 1955. Replaces E 109 - 57 T and A 272.

on with portable magnetizing equipment positioned adjacent to the piece being inspected (Fig. 1). This type of equipment may be provided with suitable switches for convenient control of the amount of the current to be used. It is recommended that ammeters be included and so positioned that the inspector can readily observe that adequate current is flowing for each inspection. Magnetizing is done by the use of portable prod contacts connected to the unit by flexible cables. A remote control switch, which may be built into the prod handles, should be provided which permits the inspector to turn the current on after the prods have been properly positioned on the part being inspected and turned off before the prods are removed. When using long cables, particular care should be taken to determine by means of the ammeter, that sufficient current is flowing.

3.2 An applicator may be used for rapid and uniform application of dry powder. Care should be taken to dust on the powder very lightly and sparingly. A low-velocity low-pressure air stream from a hand bulb or a small air hose may be used to remove excess powder. Adequate lighting should be provided to observe indications.

4. Surface Preparation

4.1 The surface being inspected shall be clean and dry. It shall be free from oil, sand, loose rust, or loose scale. As-cast or as-welded surfaces are generally satisfactory if clean. A pressure blast is useful for this purpose. Thin paint does not interfere with the formation of indications but must be removed at points where electrical contact is to be made. If the surface is unusually rough, such as with burned-in sand, or a very rough weld bead, interpretation may be difficult because the powder is being trapped mechanically. In case of doubt a light grind may be necessary to determine if actual indications are present.

5. Inspection Medium

5.1 Dry powder shall be used as the inspection medium. This material shall be of high permeability and low retentivity and of suitable sizes and shapes to produce readily magnetic particle indications. It should be of a color that will provide adequate contrast with the background of the surface being inspected. The powder shall be applied by lightly dusting a small quantity over the surface and then removing the excess with a gentle air stream. The air stream shall be so controlled that it does not disturb or remove lightly held powder patterns (Note 2). In order to recognize the broad, fuzzy, lightly held powder patterns produced by subsurface discontinuities, it is essential to observe carefully the formation of indications while the powder is being applied, and also while the excess is being removed. Adequate lighting shall be provided for easy observation of the indications (Note 3).

NOTE 2—It is recommended that the nozzle size and air pressure shall be such that, when operating in free air, a pressure of approximately 1 in. (25.4 mm) of water will be produced when measured with a manometer tube located at an axial distance of 1 in. from the nozzle.

NOTE 3—A permanent record may be made by photographs or by transfers. Transfers of any indication may easily be made by carefully pressing transparent pressure sensitive tape down over the indication. The tape is then removed with the indication adhering to it. This may then be placed on a piece of white paper, or directly on a sketch or report to form a permanent record.

6. Magnetization

6.1 *Magnetizing Technique*- Circularly magnetize the area to be inspected locally by means of contact electrodes or prods (Fig. 1). Maintain prod spacing between 6 and 8 in. (152 to 203 mm) except when the geometry of the part does not permit. In such cases, prod spacings of 2 to 4 in. (51 to 102 mm) and over 4 and less than 6 in., may be used as indicated in Table 1. Take care to prevent local overheating, arching, or burning the surface being inspected, particularly on high-carbon or alloy materials where hard spots or cracks could be produced by improper magnetizing technique. Do not turn on until after prods have been properly positioned in contact with the surface, and turn off the current before the prods are removed.

6.2 *Direction of Magnetization* -Since poor indications are produced when the discontinuities are perpendicular to current flow, the prods should be initially positioned so that the current flows essentially parallel to the direction of possible or expected discontinuities. Unless otherwise specified, make two separate inspections in each area. Make the

second inspection with the prods positioned so that the current flows approximately at right angles to the current flow used for the first inspection in that area.

6.3 *Magnetizing Current*—Use a source of direct or rectified current for magnetization. Use an average magnetizing current according to the section thickness and prod spacing as shown in Table 1. If the geometry of the part does not permit the use of the 6 to 8-in. prod spacing, use the average magnetizing current that is also shown in Table 1.

6.4 *Sequence of Operation*—Perform the inspection by the continuous method; that is, leave the magnetizing current on during the period the inspection medium is being applied and also while excess inspection medium is being removed with a gentle air stream.

7. Other Methods of Magnetic Particle Inspection

7.1 Over-all magnetization (as specified in Appendix A1) or the wet method of magnetic particle inspection may be used if such methods are more practical for certain cases. If such a method is used it shall be by mutual agreement of the manufacturer and the purchaser. The procedure for testing shall include specific details on magnetizing technique, direction or directions of magnetization, type and amount of magnetizing current, and sequence of operations.

8. Reference Photographs

8.1 Examples of discontinuities that may be found in ferrous castings and reference photographs of various degrees of severity of indications produced using dry powder and prods may be found in ASTM Reference Photographs E 125, for Magnetic Particle Indications on Ferrous Castings.[4]

9. Acceptance Standards

9.1 The acceptability of parts inspected to this method is not specified by this testing method. Acceptance standards are a matter of agreement between the manufacturer and the purchaser, or applicable specification or code.

[4] Appears in the *Annual Book of ASTM Standards*, Part 31. These reference photographs are also available on four large charts arranged for each type of discontinuity. The charts may be purchased from ASTM Headquarters. Request Adjunct No. 12-J01250-00

TABLE 1 Prod Spacing and Amperes

Prod Spacing, in. (mm)	Section Thickness, in.	
	Under 1/4 in., A	1/4 in and over, A
2[a] to 4 (51 to 102)	200 to 300	300 to 400
Over 4 (102) to less than 6 (152)	300 to 400	400 to 600
6 to 8 (152 to 203)	400 to 600	600 to 800

[a] Prod distances of less than 2 in. (51 mm) are not feasible and some other inspection method must be employed.

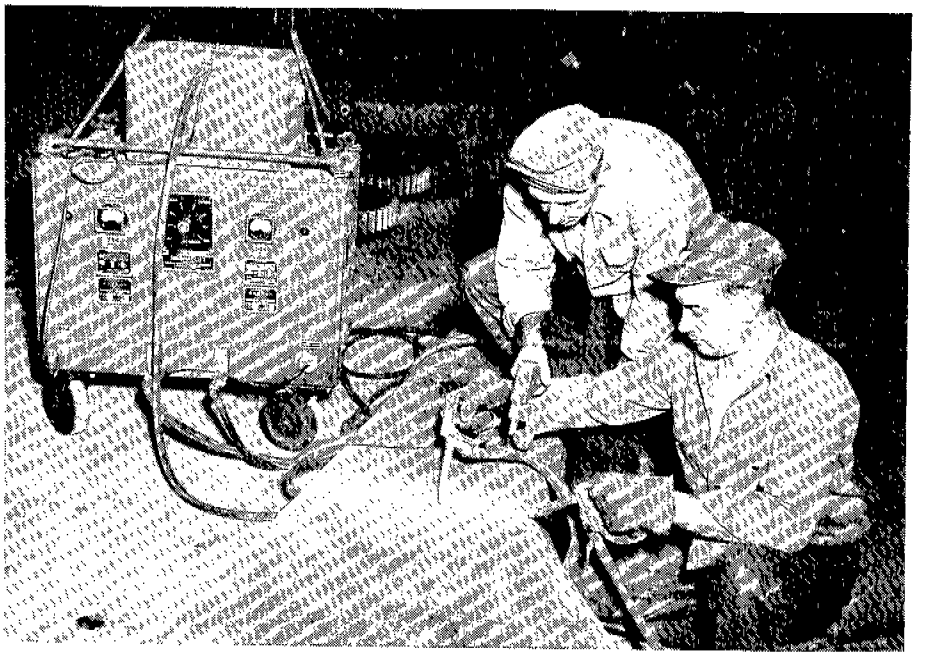

FIG. 1 Prod Inspection of Heavy Weldment with Portable Equipment (800 A, half-wave, continuous, 8 to 10-in. (203 to 254-mm) prod spacing)

Designation: E 165 – 75

American National Standard Z166.9
American National Standards Institute

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APPENDIX C

Standard Recommended Practice for LIQUID PENETRANT INSPECTION METHOD[1]

This Standard is issued under the fixed designation E 165; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This recommended practice has been approved by the Department of Defense as part of Federal Test Method Standard No. 151b and for listing in the DoD Index of Specifications and Standards. Future proposed revisions should be coordinated with the Federal Government through the Army Materials and Mechanics Research Center, Watertown, Mass. 02172.

1. Scope

1.1 This recommended practice covers procedures for liquid penetrant inspection of materials. Liquid penetrant processes are nondestructive testing methods for detecting discontinuities that are open to the surface. They are applicable to in-process, final, and maintenance inspection. They can be effectively used in the inspection of nonporous metallic materials, both ferrous and nonferrous, and of nonporous, nonmetallic materials such as ceramics, plastics, and glass. Discontinuities open to the surface such as cracks, seams, laps, cold shuts, laminations, through leaks, or lack of fusion are indicated by these methods.

1.2 This recommended practice also provides a reference:

1.2.1 By which the liquid penetrant inspection processes recommended or required by individual organizations can be reviewed to ascertain their applicability and completeness.

1.2.2 For use in the preparation of process specifications dealing with the liquid penetrant inspection of materials and parts. Agreement by the purchaser and the manufacturer regarding specific techniques is strongly recommended.

1.2.3 For use in the organization of the facilities and personnel concerned in the liquid penetrant inspection.

1.3 This recommended practice does not indicate or suggest standards for evaluation of the indications obtained. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there must be a separate code or specification or a specific agreement to define the type, size, location, and direction of indications considered acceptable, and those considered unacceptable.

2. Applicable Documents

2.1 *ASTM Standards:*

D 129, Test for Sulfur in Petroleum Products (General Bomb Method)[2]

D 808, Test for Chlorine in New and Used Petroleum Products (Bomb Method)[3]

E 270, Definitions of Terms Relating to Liquid Penetrant Inspection[4]

3. Summary

3.1 Liquid penetrant inspection methods provide a means for the detection of discontinuities that are open to the surface. In general, a liquid penetrant is applied evenly over the surface of the part being tested and allowed to enter discontinuities. After a suitable dwell time, the excess surface penetrant is removed and the part dried. A developer is then applied which draws the entrapped penetrant out of the discontinuity, staining the developer. The test part is then inspected visually to determine the presence or absence of indications.

3.2 The selection of a particular method and type of penetrant inspection procedure depends upon the nature of the application, conditions under which the inspection is to be performed,

[1] This recommended practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing.

Current edition approved April 25, 1975. Published June 1975. Originally published as E 165 – 60 T. Last previous edition E 165 – 65 (1971).

[2] *Annual Book of ASTM Standards*, Parts 23 and 40.

[3] *Annual Book of ASTM Standards*, Part 23.

[4] *Annual Book of ASTM Standards*, Part 11.

availability of processing equipment, and type of materials to perform the inspection.

3.3 Processing parameters, such as precleaning, penetration time, etc., are determined by the specific materials used, the nature of the part under inspection (that is, size, shape, surface condition, alloy), type of discontinuities expected, etc. Liquid penetrant inspection methods indicate the presence, location, and, to some extent, the nature and magnitude of the detected discontinuities.

4. Definitions

4.1 The definitions relating to liquid penetrant inspection, which appear in Definitions E 270, shall apply to the terms used in this recommended practice.

5. Classification of Methods and Types of Materials

5.1 Liquid penetrant inspection materials (see Notes 1 and 2) consist of fluorescent and visible penetrants, emulsifiers (oil-base and water-base; fast and slow acting), solvent removers, and developers. A family of liquid penetrant inspection materials consists of the applicable penetrant, emulsifier, solvent remover, and developer, as recommended by the manufacturer. Intermixing of materials from various manufacturers is not recommended. **Caution:** The inspection materials used should not adversely affect the parts tested.

NOTE 1—Refer to 7.1 for special requirements for sulfur and chlorine content.

NOTE 2—These materials can be flammable or emit hazardous and toxic vapors. Observe all manufacturers' instructions and precautionary statements

5.2 Liquid penetrant inspection methods and types are classified as indicated in Table 1.

5.2.1 *Method A*—Fluorescent penetrant inspection procedures are categorized as (*1*) water-washable (Procedure A-1), (*2*) post-emulsifiable (Procedure A-2), and (*3*) solvent-removable (Procedure A-3). **Caution:** Fluorescent penetrant inspection shall not follow a visible penetrant inspection unless the procedure is qualified in accordance with 8.2. Fluorescent penetrant inspection utilizes penetrants that fluoresce brilliantly when excited by black light (see 6.8.1.1). The sensitivity of fluorescent penetrants depends on their ability to be retained in the various size discontinuities during processing, then to bleed out into the developer coating and produce indications that fluoresce brilliantly. Fluorescent indications are many times brighter than their surroundings, hence easily visible.

5.2.1.1 *Water-Washable Penetrants* are designed to be directly water-washable from the surface of the test part, after a suitable penetration (dwell) time. Because the emulsifier is "built in" to the water-washable penetrant, it is extremely important to exercise proper process control in removal of excess surface penetrant to assure against overwashing. Water-washable penetrants can be washed out of discontinuities if the rinsing step is too long or too vigorous.

5.2.1.2 *Post-Emulsifiable Penetrants* are designed to be insoluble in water and cannot be removed with water rinsing alone. They are designed to be selectively removed from the surface of a part by the use of a separate emulsifier to aid in the removal of excess surface penetrant. The emulsifier properly applied, and when given a proper emulsification time, combines with the excess surface penetrant to form a water-washable mixture, which can be rinsed from the surface of the part, leaving the surface of the part free of fluorescent background. The penetrant that remains within the discontinuity is not as subject to overwashing. Proper emulsification time must be experimentally established and maintained to assure that over-emulsification does not occur, resulting in loss of indications.

5.2.1.3 *Solvent-Removable Penetrants* are designed so that excess surface penetrant can be removed by wiping with clean, lint-free material, and repeating the operation until most traces of penetrant have been removed. The remaining traces shall be removed by wiping the surface with clean, lint-free material lightly moistened with the solvent remover. This type is intended primarily for portability and for localized areas of inspection. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess solvent. Flushing the surface with solvent to remove the excess penetrant is prohibited.

5.2.2 *Method B*—Visible penetrant inspection makes use of a penetrant that can be seen in visible light. The penetrant is usually red in color so that the indications produce a definite contrast with the white background of the

developer. The visible penetrant process does not require the use of black light as in the case of the fluorescent penetrant process. Visible penetrant indications must be viewed, however, under adequate white light (see 6.8.2). Visible penetrant inspection procedures are categorized as (*1*) water-washable (Procedure B-1), (*2*) post-emulsifiable (Procedure B-2), and (*3*) solvent-removable (Procedure B-3).

5.2.2.1 *Visible Water-Washable Penetrants* are designed to function as described in 5.2.1.1.

5.2.2.2 *Visible Post-Emulsifiable Penetrants* are designed to function as described in 5.2.1.2.

5.2.2.3 *Visible Solvent-Removable Penetrants* are designed to function as described in 5.2.1.3.

5.3 *Emulsifiers* are liquids used to emulsify the excess oily penetrant on the surface of the part, rendering it water washable (6.5.3). There are two basic types of emulsifiers:oil-base and water-base (detergent removers), both of which can act over a range of time from a few seconds to several minutes, depending on part surface, viscosity, concentration, and chemical composition.

5.3.1 *Oil-Base Emulsifiers* are normally used as supplied and are either slow or fast acting, depending on viscosity and chemical composition. High-viscosity emulsifiers are generally slower acting than low-viscosity emulsifiers. Oil-base emulsifiers function by diffusing (dissolving) into the excess penetrant on the surface of the part and rendering it water-washable; rate of diffusion establishes emulsification time.

5.3.2 *Water-Base Emulsifiers* (detergent-type removers) are normally supplied as concentrates to be diluted with water and used as a dip or spray. Water-base emulsifiers function by displacing the excess penetrant film from the surface of the part through detergent action. The force of the water spray or air agitation of open dip tanks provides the scrubbing action while the detergent displaces the film of penetrant. The emulsification time will vary, depending on the concentration of the detergent in water.

5.4 *Solvent Removers* function by dissolving the penetrant, making it possible to wipe the surface clean and free of residual penetrant as described in 6.5.4.

5.5 *Developers*—Development of penetrant indications is the process of bringing the penetrant out of discontinuities through blotting action of the applied developer, thus increasing the visibility of the penetrant indications.

5.5.1 *Dry Powder Developers* are used as supplied (that is, free-flowing, noncaking powder) in accordance with 6.7.5. Care should be taken not to contaminate the developer with fluorescent penetrant, as the specks can appear as indications.

5.5.2 *Aqueous Wet Developers* are normally supplied as dry powders to be suspended or dissolved in water, depending on the type of aqueous wet developer.

5.5.2.1 *Aqueous Suspendible Developers* are suspensions of developer particles in water. The concentration, use, and maintenance shall be in accordance with manufacturer's recommendations (see 6.7.6).

5.5.2.2 *Aqueous Soluble Developers* are supplied as soluble powders that are dissolved in water, used at concentrations as recommended by the manufacturer (see 6.7.6).

5.5.3 *Nonaqueous Suspendible Developers* are supplied as suspensions of developer particles in nonaqueous solvent carriers ready for use as supplied. They are applied to the part by spraying after the excess penetrant has been removed and the part has dried. The nonaqueous developers are applied by conventional or electrostatic spray guns or by aerosol spray cans. This type of developer is not intended for immersion (dip-tank or flow-on) application. Nonaqueous wet developers form a white coating on the surface of the part when dried, which serves as a contrasting background for visible penetrants and developing media for fluorescent penetrants.

5.5.4 *Liquid Film Developers* are solutions or colloidal suspensions of resins/polymer in a suitable carrier. These developers will form a transparent or translucent coating on the surface of the part. Certain types of film developer may be stripped from the part and retained for record purposes.

6. Procedure

6.1 The following general processing procedures apply (see Figs. 2, 3, and 4) to both the fluorescent and visible penetrant inspection methods (see Fig. 1): As a standard technique, the temperature of the penetrant materials and the surface of the part to be processed should be

between 60 and 125°F (16 and 52°C). Where it is not practical to comply with these temperature limitations, qualify the procedure at the temperature of intended use as described in Section 8 and agreed to by the contracting parties.

6.2 *Surface Conditioning Prior to Penetrant Inspection*—Satisfactory results can usually be obtained on surfaces in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining is necessary when surface irregularities might mask the indications of unacceptable discontinuities, or otherwise interfere with the effectiveness of the examination. (See Annex A1.1.1.7 for general precautions relative to surface preparation.)

6.3 *Cleaning of Parts and Materials:*

6.3.1 *Precleaning*—The success of any penetrant inspection procedure is greatly dependent upon the surface and the discontinuity being free of any contaminant (soils) that might interfere with the penetrant process. All parts or areas of parts to be inspected must be clean and dry before the penetrant is applied. "Clean" is intended to mean that the surface must be free of any rust, scale, welding flux, spatter, grease, paint, oily films, dirt, etc., that might interfere with penetration. All of these contaminants can prevent the penetrant from entering discontinuities. Residues from cleaning processes can adversely react with the penetrant and reduce its sensitivity and performance greatly. Acids and chromates in particular greatly reduce the fluorescence of many penetrants. If only a section of a part, such as a weld, is to be inspected, the adjacent area within 1 in. (25.4 mm) of the surface to be inspected must also be cleaned. (See Annex A1 for more detailed cleaning methods.)

6.3.2 *Drying After Cleaning*—It is essential that the parts be thoroughly dry after cleaning, since any liquid residue will hinder the entrance of the penetrant. Drying may be accomplished by warming the parts in drying ovens, with infrared lamps, forced hot air, or exposure to ambient temperature. Part temperatures shall not exceed 125°F (52°C) prior to application of penetrant.

6.4 *Penetrant Application*—After the part has been cleaned, dried, and cooled to approximate ambient temperatures (125°F (52°C) maximum), apply the penetrant to the surface to be inspected so that the entire part or area under inspection is completely covered with penetrant.

6.4.1 There are various modes of effective application of penetrant such as dipping, brushing, flooding, or spraying. Small parts are quite often placed in suitable baskets and dipped into a tank of penetrant. On larger parts, and those with complex geometries, penetrant can be applied effectively by brushing or spraying. Both conventional and electrostatic spray guns are effective means of applying liquid penetrants to the part surfaces. Electrostatic spray application can eliminate excess liquid buildup of penetrant on the part, minimize overspray, and prevent penetrant from entering hollow-cored passages which can serve as penetrant reservoirs and cause severe bleedout problems during inspection of the part. Aerosol sprays are also very effective and a convenient means of application. With spray applications, it is important that there be proper ventilation. This is generally accomplished through the use of a properly designed spray booth and exhaust system.

6.4.2 After application, allow excess penetrant to drain from the part (care should be taken to prevent pools of penetrant on the part), while allowing for proper penetrant dwell time (see Table 2).

6.4.3 The length of time the penetrant must remain on the part to allow proper penetration will be as recommended by the penetrant manufacturer. Table 2 however, provides a guide for selection of penetrant dwell times for a variety of materials, their form, and types of discontinuity. If penetrant characteristics are materially affected by a prolonged dwell time, as evidenced by difficulty in removing the excess, reapply the penetrant for the original prescribed dwell time

6.5 *Removal of Excess Penetrant:*

6.5.1 After the required penetration time, remove the excess penetrant as described in 6.5.2 for water-washable penetrants, 6.5.3 for post-emulsifiable penetrants, and 6.5.4 for solvent-removable penetrants.

6.5.2 Water-washable penetrants can be removed directly from the part with water washing; they do not require an emulsification step Remove excess penetrant using manual, semi-

automatic, automatic water spray, or immersion equipment. The degree and speed of removal will depend on such processing parameters as water pressure, water temperature, and duration of rinse cycle. The inherent removal characteristics of the penetrant employed, as well as the surface condition of the part, will also affect the speed and degree of removal. It is important that the water-rinsing operation be controlled.

6.5.2.1 Water pressure should be constant and should not exceed 50 psi (345 kPa) (30 psi (205 kPa) is an average value). Generally, a coarse spray is recommended.

6.5.2.2 Maintain the temperature of the water at a relatively constant temperature. Most water-washable penetrants can be removed effectively within a water-wash temperature range from 60 to 110°F (16 to 43°C), but for consistent results, maintain them at the temperature recommended by the penetrant supplier.

6.5.2.3 The duration of the rinse cycle will depend on the inherent removal characteristics of the penetrant, the surface condition of the part, and the water spray pressure and temperature employed; determine it experimentally for the particular application. The optimum time will be evident when no interfering background remains.

6.5.2.4 Avoid overwashing; excessive washing can cause penetrant to be washed out of discontinuities. Perform the rinsing operation for Method A under black light so that it can be determined when the surface penetrant has been adequately removed.

6.5.2.5 In special applications, where water rinse facilities are not available, penetrant removal may be performed by wiping the surface with a clean, absorbent material dampened with water until the excess surface penetrant is removed.

6.5.3 Post-emulsifiable penetrants are not directly water washable; they require the use of an emulsifier (oil or water base). After the required penetration time, emulsify the excess penetrant on the part by dipping, flooding, or spraying the parts with the required emulsifier (the emulsifier combines with the excess penetrant and makes the mixture removable with water rinsing). After application of the emulsifier, drain the parts in a manner that prevents the emulsifier from pooling on the part.

6.5.3.1 Emulsification dwell time begins as soon as the emulsifier has been applied. The length of time that the emulsifier is allowed to remain on the part and in contact with the penetrant is dependent on the type of emulsifier employed (fast acting, slow acting, oil base, or water base) and the surface condition of the part (smooth or rough). *Nominal emulsification time should be as recommended by the manufacturer.* Determine experimentally the actual emulsification time for each specific application. The surface finish (roughness) of the part is a significant factor in the selection of and in the emulsification time of an emulsifier. In general, it can range from a few seconds to several minutes, depending on the activity of the emulsifier.

6.5.3.2 Effective rinsing of the emulsified penetrant from the surface of the part can be accomplished using either manual, semiautomatic, or automatic water spray or immersion equipment. For Method A, perform the water rinsing operation under black light so that it can be determined when the surface penetrant has been adequately removed. Residual background should be minimal so that it does not interfere with the inspection of the part and yet indicates that over-emulsification has not occurred.

6.5.3.3 Water pressure should be constant and should not exceed 50 psi (345 kPa) (30 psi (205 kPa) average). Generally, a coarse spray is recommended.

6.5.3.4 Maintain the temperature of the water at a relatively constant temperature. Water temperatures in the range from 60 to 110°F (16 to 43°C) are effective

6.5.4 With solvent-removable penetrants, remove excess penetrant, insofar as possible, by using wipes of clean, lint-free material, repeating the operation until most traces of penetrant have been removed. Then *lightly* moisten with solvent a lint-free material and wipe the surface until all remaining traces of excess penetrant have been removed. To minimize removal of penetrant from discontinuities, take care to avoid the use of excess solvent. Flushing the surface with solvent following the application of the penetrant and prior to developing is prohibited.

6.6 *Drying of Parts:*

6.6.1 During the preparation of parts for inspection, drying is necessary either following the application of the aqueous wet developer or to dry the rinse water preceding the use of dry or nonaqueous developers.

6.6.2 Parts can be dried by using a hot-air recirculating oven, a hot-air blast, or by exposure to ambient temperature. Drying is best done in a thermostatically controlled recirculating hot-air dryer. The temperature in the dryer is normally maintained between 175 and 225°F (79 and 107°C) for most applications. **Caution:** Part temperature should not exceed 125°F (52°C). Local heating or cooling is permitted provided the temperature of the part remains in the range from 60 to 125°F (16 to 52°C), unless otherwise agreed to by the contracting parties

6.6.3 Do not allow parts to remain in the drying oven any longer than is necessary to dry the part. Excessive time in the dryer can cause damage to the part as well as evaporation of the penetrant, which can impair the sensitivity of the inspection. Drying time will vary with the size, nature, and number of parts under inspection.

6.6.4 In the case of solvent-removable penetrants (6.4.4) where excess penetrant is removed with solvent wipe-off technique, dry the surface by normal evaporation. Normally, no other drying techniques are necessary, so long as the processing temperature range is within 60 to 125°F (16 to 52°C).

6.7 *Developing Indications:*

6.7.1 Developing the penetrant indications is the process of bringing the penetrant back out of the discontinuities through blotting action and spreading it out on the surface to increase its visibility to the eye.

6.7.2 Use developers either dry or suspended in an aqueous or nonaqueous solvent that is evaporated to dryness before inspection to form a particulate or resin/polymer liquid film.

6.7.3 Apply developers immediately after the excess penetrant has been removed from the part surface, prior to drying in the case of aqueous developers, and immediately after the part has been dried for all other developer forms.

6.7.4 There are various modes of effective application of the various types of developers such as dipping, immersing, flooding, spraying, or dusting. The size configuration, surface condition, number of parts to be processed, etc., will influence the choice of developer.

6.7.5 Apply dry powder developers after drying, in accordance with 6.6. Apply dry powder developers in such a manner as to assure complete part coverage. Parts can be immersed or dipped into a container of dry developer or dipped into a fluid bed of dry developer; they can also be dusted with the powder developer through a hand powder bulb or a powder gun. It is quite common and most effective to apply dry powder in an enclosed dust chamber, which creates an effective and controlled dust cloud. Excess powder may be removed by shaking or tapping the part gently, or by blowing with low-pressure (5 to 10 psi (34 to 69 kPa)) dry, clean, compressed air. Other means suited to the size and geometry of the specimen may be used provided the powder is dusted evenly over the entire surface being examined. Parts can be sprayed with a conventional or electrostatic powder spray gun.

6.7.6 Apply aqueous developers to the part immediately after the excess penetrant has been removed from the part and prior to drying. The dried developer appears as a white coating on the part. Prepare and maintain aqueous developers in accordance with the manufacturer's instructions and apply them in such a manner as to assure complete, even, part coverage. Exercise caution when using a wet developer with water-washable penetrants to avoid possible loss of indications.

6.7.6.1 Apply aqueous developers by spraying, flowing, or immersing the part. With aqueous wet developers, it is most common to immerse the parts in the prepared developer bath. Immerse parts only long enough to coat all of the part surfaces with the developer. Then remove parts from the developer bath and allow to drain. Drain all excess developer from recesses and trapped sections to eliminate tendencies of pooling of developer, which can obscure discontinuities.

6.7.6.2 Then dry the parts in accordance with 6.6.

6.7.7 Apply nonaqueous wet developers to the part by spraying after the excess penetrant has been removed and the part has been dried. This type of developer evaporates very rapidly

at normal room temperature and does not, therefore, require the use of a dryer. It should be used, however, with proper ventilation.

6.7.7.1 Apply nonaqueous developers by spray application as recommended by the manufacturer. Spray parts in such a manner as to assure complete part coverage with a thin, even film of developer.

6.7.7.2 Dipping or flooding parts with nonaqueous developers is prohibited, since it will flush (dissolve) the penetrant from within the discontinuities through its solvent action.

6.7.8 Apply liquid film-type developers by spraying or dipping as recommended by the manufacturer. Spray parts in such a manner as to assure complete part coverage with a thin, even film of developer.

6.7.9 The length of time the developer is to remain on the part prior to inspection should not be less than 7 min. Developing time begins immediately after the application of dry powder developer and as soon as the wet (aqueous and nonaqueous) developer coating is dry (that is, the solvent carriers have evaporated to dryness). If bleedout does not alter the inspection results, development periods of over 30 min are permitted.

6.8 *Inspection*—Perform inspection of parts after the applicable development time as specified in 6.7.9 to assure proper bleedout of penetrant from discontinuities onto the developer coating. It is good practice to observe the surface while applying the developer as an aid in evaluating indications.

6.8.1 Inspect fluorescent penetrant indications in a darkened area. A maximum of 3 footcandles (32 lx) ambient light is allowed for critical inspection. Higher levels may be used for noncritical inspections if darkness is unobtainable.

6.8.1.1 Measure black light intensity, at a recommended minimum of 800 $\mu W/cm^2$ on the surface of the part being inspected, with a suitable black light meter. Check black light intensity periodically (every 30 days is recommended) to assure the required output. Drops in line voltage can be the cause of decreased black light output and should be checked periodically. If line voltage fluctuations exist which cause inconsistent black light performance, use a constant voltage transformer.

6.8.1.2 Allow the black light to warm up for a minimum of 5 min prior to its use or measurement of the intensity of the ultraviolet light emitted.

6.8.1.3 It is recommended that the inspector be in the darkened inspection area for at least 5 min prior to inspection so that his eyes will adapt to dark viewing.

6.8.1.4 Keep the inspection area free of interfering debris. Practice good housekeeping at all times.

6.8.2 Visible penetrant indications can be inspected in either natural or artificial white light. Adequate illumination is required to ensure no loss of the sensitivity in the inspection. A minimum light intensity at the inspection site of 32.5 footcandles (350 lx) is recommended.

6.9 *Post Cleaning*—Post cleaning is necessary in those cases where residual penetrant or developer could interfere with subsequent processing or with service requirements. It is particularly important where residual penetrant inspection materials might combine with other factors in service to produce corrosion. A suitable technique, such as a simple water rinse, machine wash, vapor degreasing, solvent soak, or ultrasonic cleaning may be employed (see A1.2). In the case of developers, it is recommended that if post removal is necessary, that it be carried out as promptly as possible after inspection so that it does not fix on the part. Water spray rinsing is generally adequate. (**Caution:** Developers should be removed prior to vapor degreasing. Vapor degreasing can bake developer on parts.)

7. Special Requirements

7.1 *Sulfur and Chlorine Content*—When using penetrant inspection materials on austenitic stainless steels, titanium, or nickel-base alloys, the need to restrict chloride ion content, total chlorine content, and sulfur content should be considered. If such a need exists, sampling techniques and analytical test methods and limits should be agreed upon between contracting parties. In the absence of a specific requirement, the chlorine content should be limited to 1 % where potential use includes application to austenitic stainless steel or titanium. Method D 808 can provide reliable analytical results for total chloride contents of 1000 ppm (0.1 %) or more. Similarly, in the

absence of a specific requirement, the sulfur content should be limited to 1 % where potential use includes application to nickel-base alloys at elevated temperatures. Method D 129 can provide reliable analytical results for sulfur contents of 1000 ppm (0.1 %) or more.

7.2 Where penetrant inspection is performed on parts that must be maintained at elevated temperature during inspection, special materials and processing techniques may be required. Such inspection requires qualification in accordance with 8.1. Manufacturer's recommendations should be observed.

8. Qualification and Requalification

8.1 Qualification of procedures requires proof of equivalence to the currently approved procedure. Equivalency is determined by direct comparison on penetrant comparators or representative test parts, or both, as mutually agreed to by the contracting parties.

8.2 Requalification is required when a change or substitution is made in the type of penetrant materials or in the processing technique.

TABLE 1 Classification of Liquid Penetrant Inspection Methods and Types

Method A—Fluorescent, Liquid Penetrant Inspection
Type 1—water-washable (Procedure A-1) Type 2—post-emulsifiable (Procedure A-2) Type 3—solvent-removable (Procedure A-3)
Method B—Visible, Liquid Penetrant Inspection
Type 1—water-washable (Procedure B-1) Type 2—post-emulsifiable (Procedure B-2) Type 3—solvent-removable (Procedure B-3)

TABLE 2 Recommended Dwell Times

Material	Form	Type of Discontinuity	Dwell Times (in minutes) for Methods A-1, A-2, A-3, B-1, B-2, B-3[a, b]	
			Penetrant[c]	Developer[d]
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	*cast*—castings and welds	cold shuts, porosity, lack of fusion, cracks (all forms)	5	7
	wrought—extrusions, forgings, plate	laps, cracks (all forms)	10	7
Carbide-tipped tools		lack of fusion, porosity, cracks	5	7
Plastic	all forms	cracks	5	7
Glass	all forms	cracks	5	7
Ceramic	all forms	cracks, porosity	5	7

[a] For temperature range from 60 to 125°F (15 to 50°C)
[b] All dwell times given are recommended minimums
[c] Maximum penetrant dwell time 60 min, in accordance with 6.4.3
[d] Development time begins directly after application of dry developer and as soon as wet developer coating has dried on surface of parts (recommended minimum)

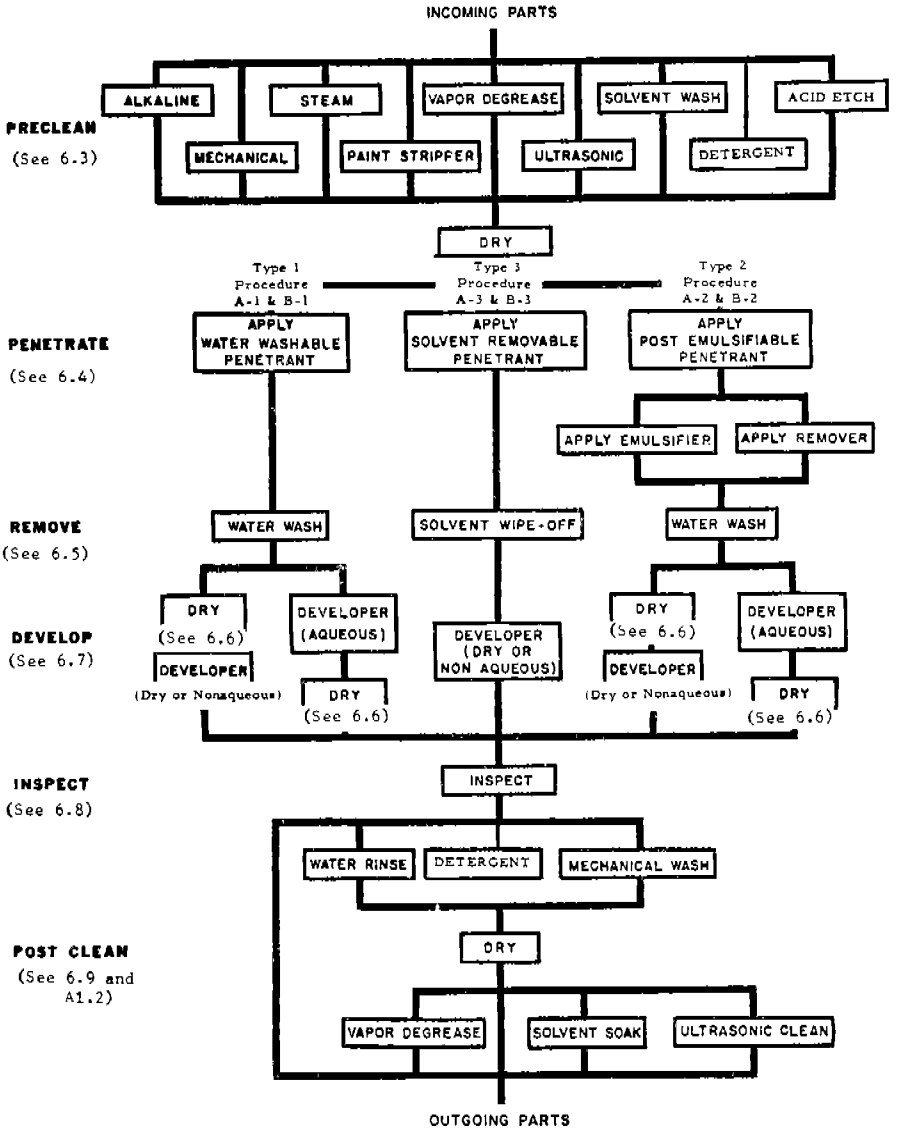


FIG. 1 Fluorescent and Visible Penetrant Inspection General Processing Procedures Flowsheet.

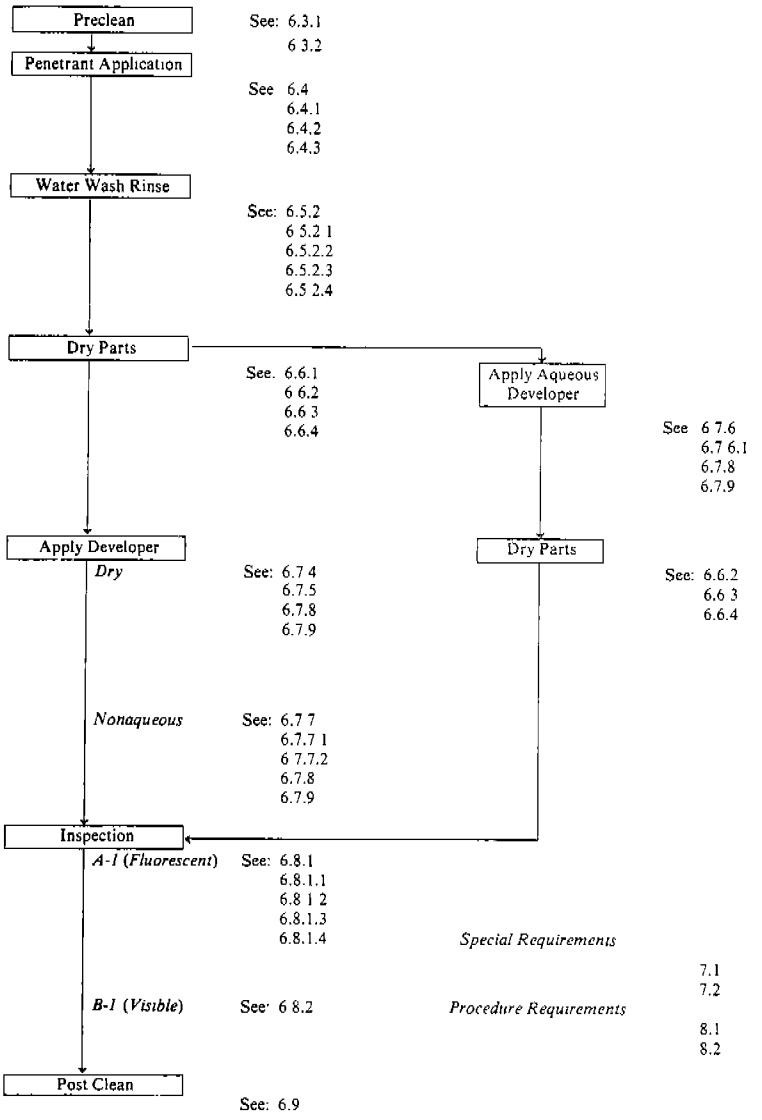


FIG. 2 Type 1—Water-Washable Penetrant Inspection Processing Procedures A-1 (Fluorescent) and B-1 (Visible).

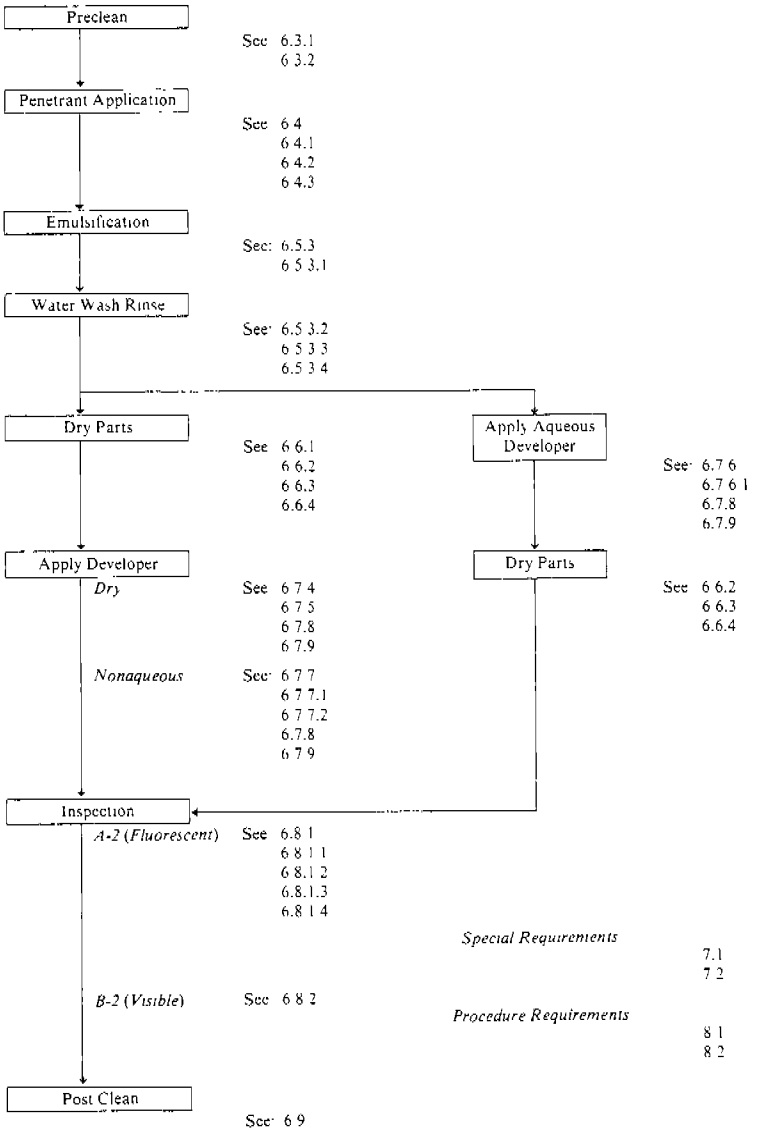


FIG. 3 Type 2—Post Emulsifiable Procedures A-2 (Fluorescent) and B-2 (Visible).

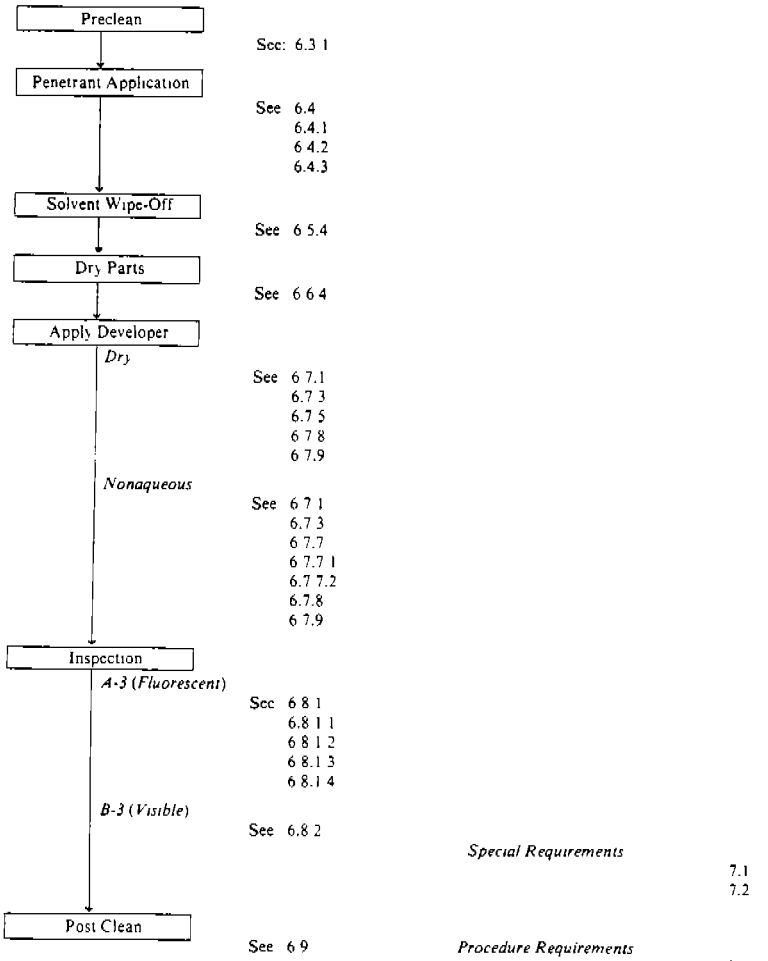


FIG. 4 Type 3—Solvent Removable Penetrant Inspection Processing Procedures A-3 (Fluorescent) and B-3 (Visible).

ANNEX

A1. CLEANING OF PARTS AND MATERIALS

A1.1 Choice of Cleaning Method

A1.1.1 The choice of a suitable cleaning method is based on such factors as: (*1*) type of contaminant to be removed since no one method removes all contaminants equally well; (*2*) effect of the cleaning method on the parts; (*3*) practicality of the cleaning method for the part (for example, a large part cannot be put into a small degreaser or ultrasonic cleaner); and (*4*) specific cleaning requirements of the purchaser. The following cleaning methods are recommended.

A1.1.1.1 *Detergent Cleaning*—Detergent cleaners are nonflammable water-soluble compounds containing specially selected surfactants for wetting, penetrating, emulsifying, and saponifying various types of

soils, such as grease and oily films, cutting and machining fluids, and unpigmented drawing compounds, etc. Detergent cleaners may be alkaline, neutral, or acidic in nature, but must be noncorrosive to the item being inspected. The cleaning properties of detergent solutions facilitate complete removal of soils and contamination from the surface and void areas, thus preparing them to absorb the penetrant. Cleaning time should average 10 to 15 min at 170 to 200°F (77 to 93°C) with moderate agitation, using concentrations (generally 6 to 8 oz/gal or 45 to 60 kg/m³) recommended by the manufacturer of the cleaning compound.

A1.1.1.2 *Solvent Cleaning*—There are a variety of solvent cleaners that can be effectively utilized to dissolve such soils as grease and oily films, waxes and sealants, paints, and in general, organic matter. These solvents should be residue-free, especially when used as a hand-wipe solvent or as a dip-tank degreasing solvent. Solvent cleaners are not recommended for the removal of rust and scale, welding flux and spatter, and in general, inorganic soils. **Caution:** Some cleaning solvents are flammable and can be toxic. Observe all manufacturers' instructions and precautionary notes.

A1.1.1.3 *Vapor Degreasing*—Vapor degreasing is a preferred method of removing oil or grease-type soils from the surface of parts and from open discontinuities. It will not remove inorganic-type soils (dirt, corrosion, salts, etc.), and may not remove resinous soils (plastic coatings, varnish, paint, etc.). Because of the short contact time, degreasing may not completely clean out deep discontinuities and a subsequent solvent soak is recommended.

A1.1.1.4 *Alkaline Cleaning:*

(*a*) Alkaline cleaners are nonflammable water solutions containing specially selected detergents for wetting, penetrating, emulsifying, and saponifying various types of soils. Hot alkaline solutions are also used for rust removal and descaling to remove oxide scale which can mask surface discontinuities. Alkaline cleaner compounds must be used in accordance with the manufacturers' recommendations. **Caution:** Parts cleaned by the alkaline cleaning process must be rinsed completely free of cleaner and thoroughly dried by heat prior to the penetrant inspection process (part temperature at the time of penetrant application shall not exceed 125°F (52°C).

(*b*) Steam cleaning is a modification of the hot-tank alkaline cleaning method, which can be used for preparation of large, unwieldy parts. It will remove inorganic soils and many organic soils from the surface of parts, but may not reach to the bottom of deep discontinuities, and a subsequent solvent soak is recommended.

A1.1.1.5 *Ultrasonic Cleaning*—This method adds ultrasonic agitation to solvent or detergent cleaning to improve cleaning efficiency and decrease cleaning time. It should be used with water and detergent if the soil to be removed is inorganic (rust, dirt, salts, corrosion products, etc.), and with organic solvent if the soil to be removed is organic (grease and oily films, etc.). After ultrasonic cleaning, parts should be heated to remove the cleaning fluid, then cooled to at least 125°F (52°C), before application of penetrant.

A1.1.1.6 *Paint Removal*—Paint films can be effectively removed by bond release solvent paint remover or disintegrating-type hot-tank alkaline paint strippers. In most cases, the paint film must be completely removed to expose the surface of the metal. Solvent-type paint removers can be of the high-viscosity thickened type for spray or brush application or can be of low viscosity two-layer type for dip-tank application. Both types of solvent paint removers are generally used at ambient temperatures, as received. Hot-tank alkaline strippers are water-soluble powder compounds generally used at 8 to 16 oz/gal (60 to 120 kg/m³) of water at 180 to 200°F (82 to 93°C). After paint removal, the parts must be thoroughly rinsed to remove all contamination from the void openings and then thoroughly dried.

A1.1.1.7 *Mechanical Cleaning and Surface Conditioning*—Metal-removing processes such as filing, buffing, scraping, mechanical milling, drilling, reaming, grinding, liquid honing, sanding, lathe cutting, tumble or vibratory deburring, and abrasive blasting, including abrasives such as glass beads, sand, aluminum oxide, ligno-cellulose pellets, metallic shot, etc., are often used to remove such soils as carbon, rust and scale, and foundry adhering sands, as well as to deburr or produce a desired cosmetic effect on the part. *These processes may decrease the effectiveness of the penetrant examination by smearing or peening over metal surfaces and filling discontinuities open to the surface, especially for soft metals such as aluminum, titanium, magnesium, and beryllium alloy.*

A1.1.1.8 *Acid Etching*—Inhibited acid solutions (pickling solutions) are routinely used for descaling part surfaces. Descaling is necessary to remove oxide scale, which can mask surface discontinuities and prevent penetrant from entering. Acid solutions/etchants are also used routinely to remove smeared metal that peens over surface discontinuities. Such etchants should be used in accordance with the manufacturers' recommendations. **Caution:**

NOTE A1—Etched parts and materials must be rinsed completely free of etchants, the surface neutralized and thoroughly dried by heat prior to application of penetrants. Acids and chromates can adversely affect the fluorescence of fluorescent materials.

NOTE A2—Whenever there is a possibility of hydrogen embrittlement as a result of acid solution/etching, the part should be baked at a suitable temperature for an appropriate time to remove the hydrogen before further processing. After baking, the part shall be cooled to a temperature below 125°F (52°C) before applying penetrants.

A1.1.1.9 *Air Firing of Ceramics*—Heating of a ceramic part in a clean, oxidizing atmosphere is an effective way of removing moisture or light organic soil or both. The maximum temperature that will not cause degradation of the properties of the ceramic should be used.

A1.2 **Post Cleaning**

A1.2.1 *Removal of Developer*—Dry powder developer can be effectively removed with an air blow-off (free of oil) or it can be removed with water rinsing. Wet developer coatings can be removed effectively by water rinsing or water rinsing with detergent either by hand or with a mechanical assist (scrub brushing, washing machine, etc.). The soluble

developer coatings simply dissolve off of the part with a water rinse

A1.2.2 Residual penetrant may be removed through solvent action. Vapor degreasing (10 min minimum), solvent soaking (15 min minimum), and ultrasonic solvent cleaning (3 min minimum) techniques are recommended. In some cases, it is desirable to vapor degrease, then follow with a solvent soak. The actual time required in the vapor degreaser and solvent soak will depend on the nature of the part and should be determined experimentally.

APPENDIX D

The Contact Ultrasonic Inspection of Welds*

Test Method

General - The procedures given apply to the contact ultrasonic inspection of butt welds. Weld inspection is accomplished by introducing shear waves into a plate at a selected angle and manipulating the search unit (transducer) so as to scan the entire weld. (Fig. D.1)

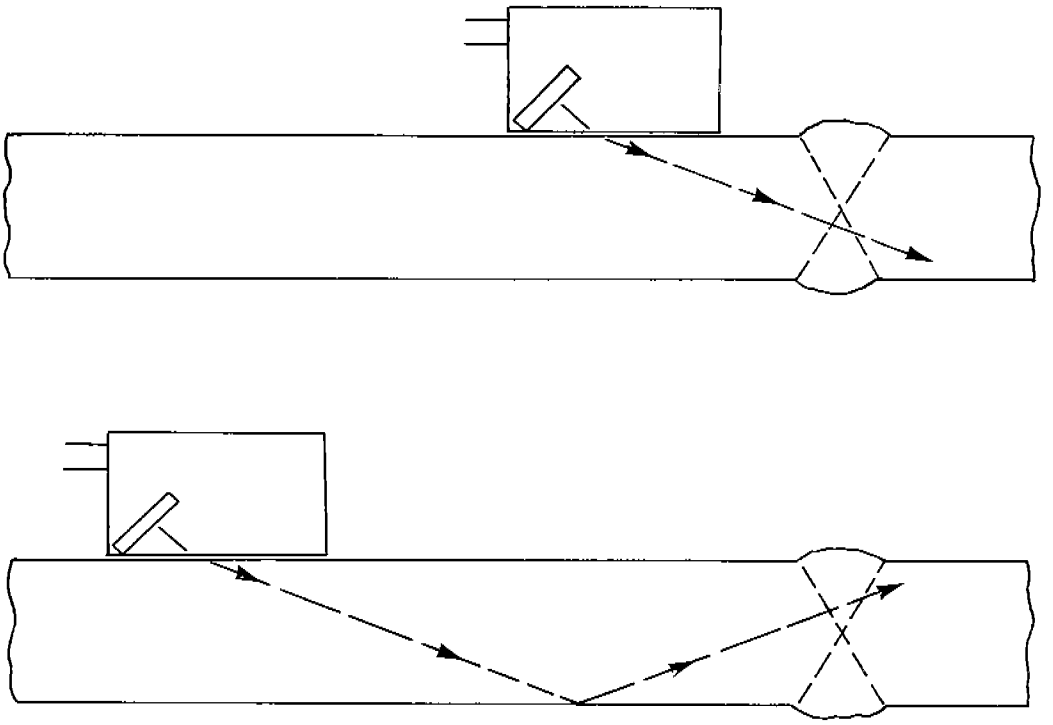


Fig. D-1 - Technique for Inspecting Butt Welds with Shear Waves.

*Abridged version of A Guide for Ultrasonic Testing and Evaluation of Weld Flaws by R. A. Youshaw, SSC-213, Ship Structure Committee, Washington, D.C. 1970.

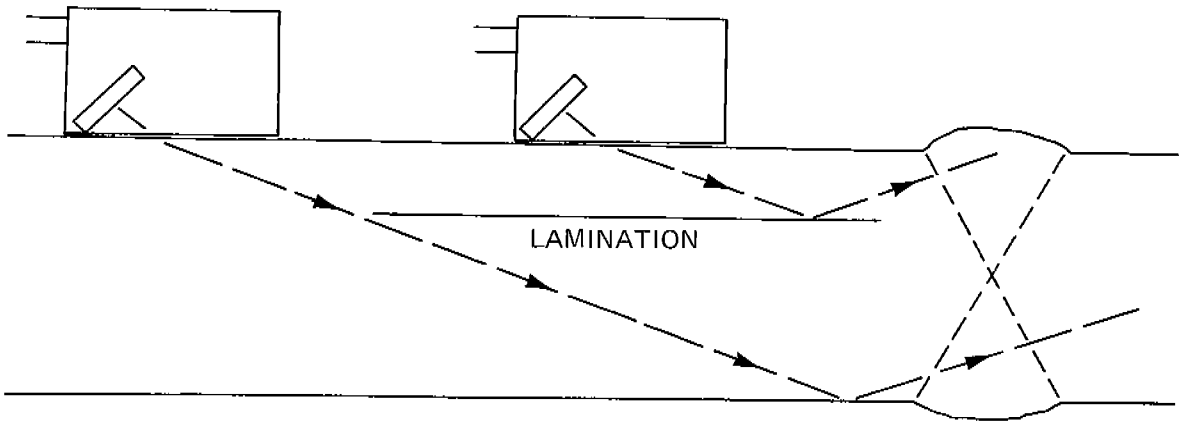


Fig. D-2 - Masking Effect of a Base Metal Lamination

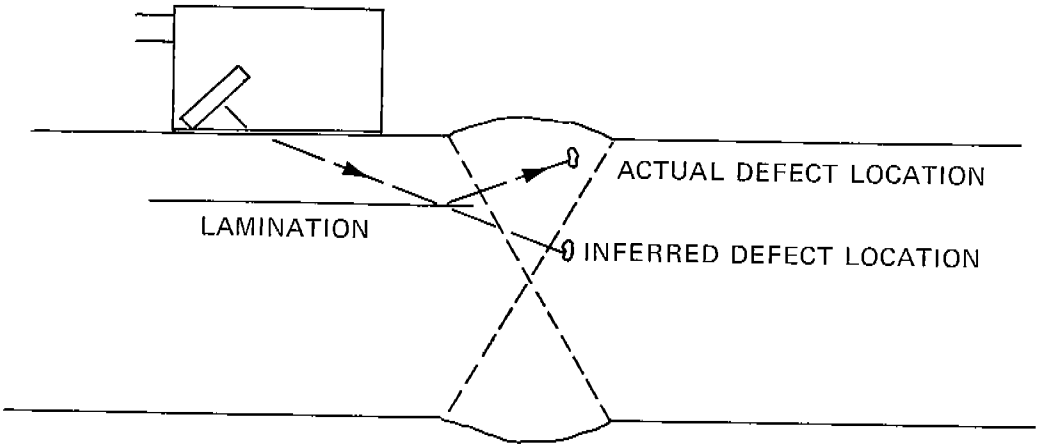


Fig. D-3 - Position Errors Introduced by Base Metal Lamination

Equipment - The ultrasonic instrument shall be of the pulse-echo type with an A-scan Presentation. It shall be capable of generating, receiving, and displaying screen pulses from 1 to 5 MHz on the cathode ray tube. The instrument shall have a circuitry to provide a continuously increasing amplification with respect to time or distance of travel. A calibrated decibel attenuator control is recommended. Battery powered equipment must contain an alarm to signal battery depletion prior to instrument shut-off due to battery exhaustion.

Search Unit - The maximum dimension (manufacturers' specifications) of the transducer active element shall not exceed one inch. A ratio of 2:1 width to height of the active element is recommended. A nominal test frequency of 2.25 MHz is recommended. The transducer shall be mounted on a suitable wedge to produce the recommended shear wave angle in the material being inspected. The following shear wave angles are recommended:

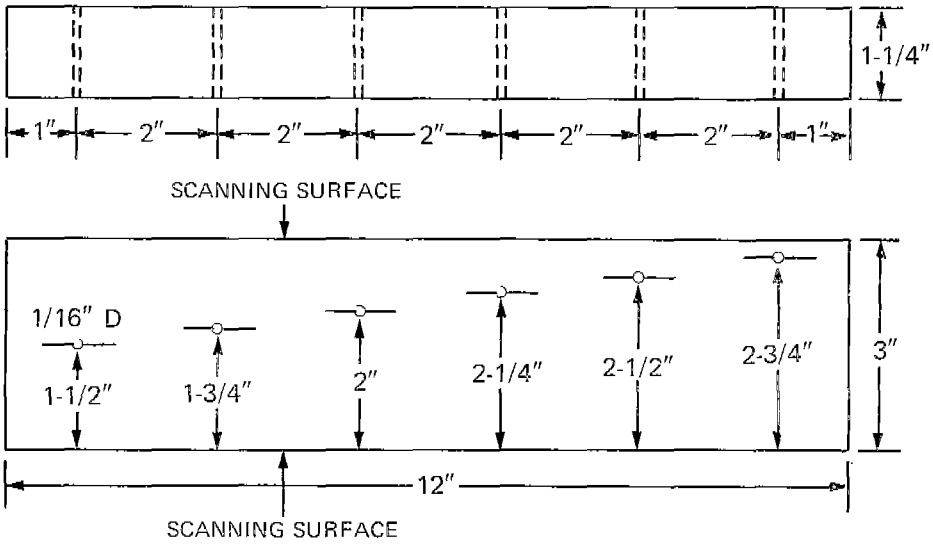
60^{o} or 70^{o} for plate thicknesses 1/2 inch to 1-1/2 inch

45^{o} or 60^{o} for plate thicknesses 1-1/2 inch to 3 inches

Couplant - A liquid such as glycerin diluted with alcohol or water and to which a wetting agent has been added is recommended for acoustic coupling between the transducer and the plate. Most oils are acceptable. For overhead work and for places of difficult access certain types of grease may prove useful. Any couplant should be removed upon completion of the inspection.

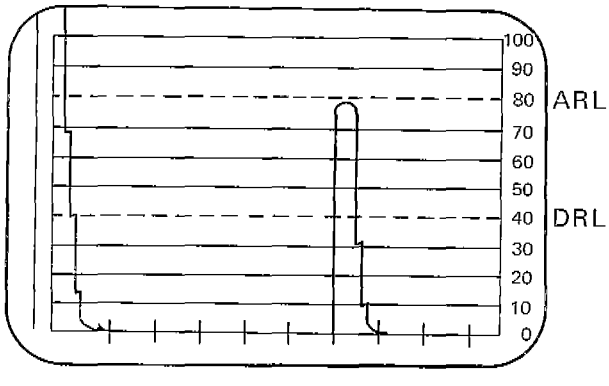
Surface Preparation - The average plate as received from the mill has a surface that is smooth enough for ultrasonic inspection. Plate with loose scale, flaked paint, excess rust, or pitting will require grinding. After welding, the surface of the base metal where the probe is to be manipulated should be cleaned of weld splatter. If surface irregularities on the weld bead cause difficulties in interpretation, the weld bead should be ground sufficiently smooth to permit adequate inspection.

Base Metal Inspection - Although the presence of laminations in the base metal may not be a basis for rejection, these reflectors may mask a part of the weld from the ultrasonic beam, (Fig. D-2), or cause the operator to incorrectly locate a discontinuity, (Fig. D-3). Laminations can be detected ultrasonically with a straight beam (longitudinal waves). When laminations are encountered, the inspection should be made from the other side of the weld.



SURFACE FINISH ON THE SCANNING SURFACES TO BE APPROXIMATELY 250 RMS PREPARED BY GRINDING METHOD WITH THE DIRECTION OF GRIND PARALLEL TO THE LONG DIMENSIONS OF THE BLOCK.

Fig. D-4 - Typical Reference Calibration Standard for Angle Beam Scanning



NOTE: CALIBRATION IS PERFORMED WITH THE REFLECTION OBTAINED FROM THE WALL OF A 1/16" DRILLED HOLE USING DISTANCE-AMPLITUDE CORRECTIONS.

Fig. D-5 - Typical Viewing Screen Calibration for Instruments Without Decibel Attentuation Controls

CALIBRATION STANDARDS

A test block shall be prepared from material experimentally determined to be defect free and which is acoustically similar to the work material. This block should be 1-1/4 inches thick with a series of 3/64-inch diameter drilled holes spaced to provide path lengths equivalent to the longest and shortest path lengths to be used in the weld inspection. Intermediate distances should also be provided. The scanning surfaces should be approximately 250 RMS, prepared by the grinding method with the direction of grind parallel to the long dimension of the test block. Fig. D-4 illustrates an acceptable design.

INSTRUMENT CALIBRATION

Two levels of signal amplitude are defined in this Appendix - ARL (Amplitude Reject Level) and DRL (Disregard Level). These two levels are established as follows:

The delay controls are used to position the initial pulse at the left of the viewing screen at a location marked zero on a reticule or screen scale. The instrument range controls can then be adjusted to display signals from the reference calibration drilled holes for the distances to be considered.

The distance amplitude correction controls are to be adjusted to compensate for signal loss due to distance of travel, i.e., the height of signals from all the reference drilled holes should be made equal.

The instrument gain control is to be adjusted to set the equalized signals from the reference reflectors at 60% of full screen height, (Fig. D-5). For this setting the 40% line shall be the DRL and the 80% line shall be the ARL, (Fig. D-5).

The ultrasonic instrument shall be calibrated at the job-site; and verified at least once every four-hour interval thereafter. The calibration shall be verified whenever the instrument is jarred, or moved to a new location; and at any instance of questionable performance.

WELD INSPECTION

Longitudinal defects are found by directing the sound beam normal to the length of the weld and moving the transducer back and forth to scan the entire weld

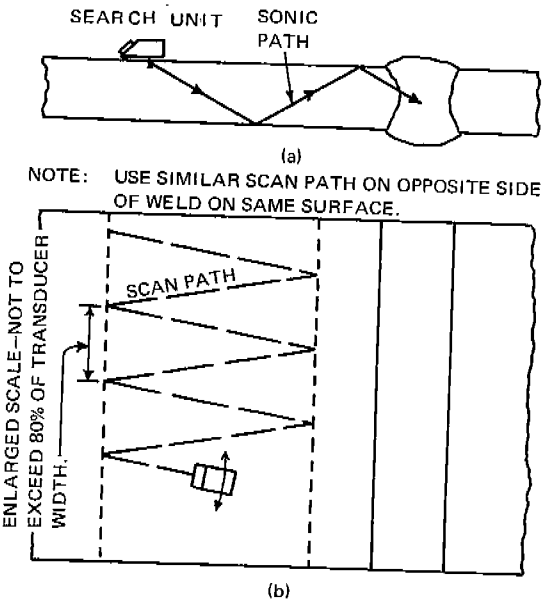


Fig. D-6 - Technique for Inspecting Butt Welds with Shear Waves

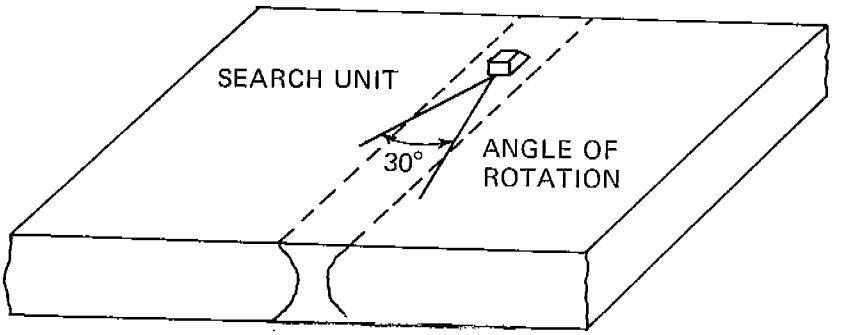


Fig. D-7 - Supplementary Technique for Inspecting Butt Welds when the Weld Bead is Ground Flush

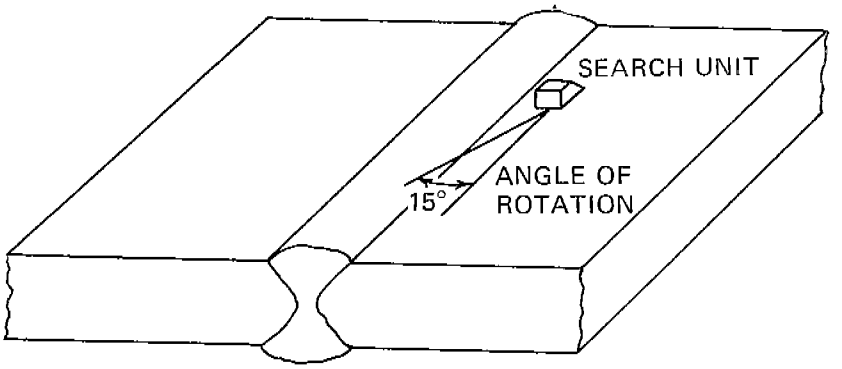


Fig. D-8 - Supplementary Technique for Inspecting Butt Welds when the Weld Bead is not Ground Flush

as shown in Fig. D-6. Simultaneously, the transducer is oscillated through a small angle. The back and forth motions should be repeated at intervals which do not exceed 80% of the width of the transducer as the probe is moved along the weld.

Transverse defects are detected as follows:

a. For welds ground smooth the transducer is placed on top of the weld and moved along its length , (Fig. D-7).

b. For welds not ground smooth the transducer is placed along-side and not quite parallel to the weld and moved along the length, (Fig. D-8)

The entire weld and heat affected zone should be scanned. The weld should be inspected in two opposing directions, e.g., Fig. D-9, a--e.

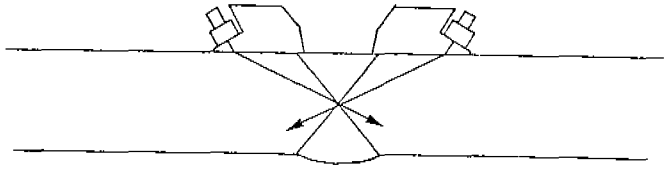
DISCONTINUITY LENGTH DETERMINATIONS

When discontinuities are detected, the sound beam should be directed so as to maximize the signal amplitude. The transducer is then moved parallel to the discontinuity and away from the position of maximum signal amplitude. The extremity of the discontinuity is defined as the point at which the signal amplitude drops to one half of the peak value. This point is marked using the centerline of the wedge as an index. In a similar manner, the other extremity is found and the distance between marks is defined as the length of the discontinuity. The minimum recordable length of a discontinuity shall be 1/8-inch.

RECORD OF INSPECTION

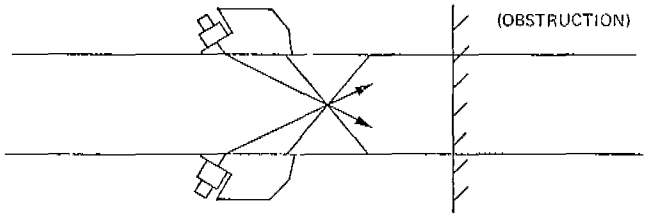
The record of each weld inspection should include:

1. Operator's identity
2. Date
3. Instrument identity
4. Transducer type, size, frequency and angle
5. Identification of test object
6. Location of the weld
7. Type of material
8. Thickness of base plate
9. Type of joint and configuration
10. Condition of the weld bead
11. Couplant
12. Flaw data
13. Inspection coverage, including reference points



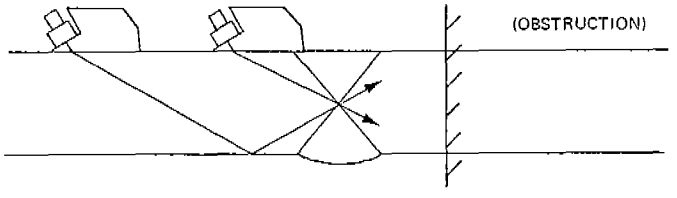
USE HALF SKIP (OVERLAPPING WELD COMPLETELY) FROM BOTH SIDES OF THE WELD ON THE SAME SURFACE OF THE PLATE

Fig. D-9-a - Minimum Scanning Procedure with Weld Bead Flush and Both Sides of Weld Accessible.



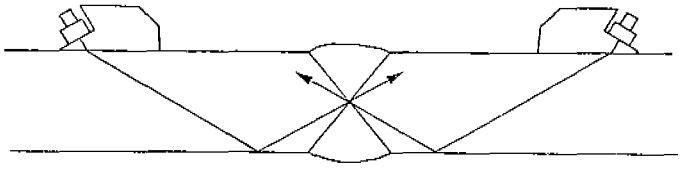
USE HALF SKIP (OVERLAPPING THE WELD COMPLETELY) ON BOTH SURFACES OF PLATE ON SAME SIDE OF WELD

Fig. D-9-b - Minimum Scanning Procedure with Both Welds Flush-Ground and One Side of Weld Obstructed.



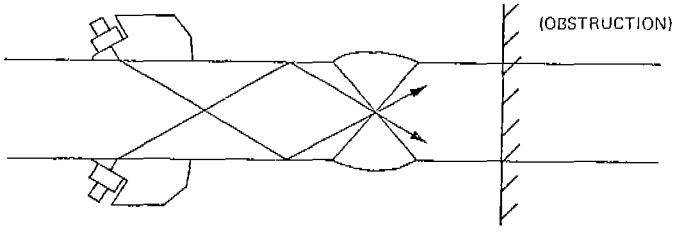
USE BOTH FULL AND HALF SKIP (OVERLAPPING THE WELD) FROM ONE SURFACE ON SAME SIDE OF WELD

Fig. D-9-c - Minimum Scanning Procedure with only One Weld Bead Flush-Ground and One Side of Weld Obstructed.



USE FULL SKIP ON BOTH SIDES OF WELD FROM SAME SURFACE OF PLATE

Fig. D-9-d - Minimum Scanning Procedure with Weld Bead not Flush-Ground and Both Sides of Weld Accessible.



USE FULL SKIP ON BOTH SURFACES OF PLATE FROM SAME SIDE OF WELD

Fig. D-9-e - Minimum Scanning Procedure with Weld Bead not Flush-Ground and One Side of Weld Obstructed.

GLOSSARY OF TERMS

A-Scan - A method of data presentation on a cathode ray tube utilizing a horizontal base line which indicates elapsed time when reading from left to right. A vertical deflection from the base line indicates reflected s signal amplitudes.

Acoustically Similar - The same type of material as that to be inspected, or another material which has been experimentally proven to have acoustic velocity within +3% and an attenuation for shear waves at the frequency to be used within ±0.25 dB/inch of the material to be inspected.

Active Element - The piezo-electrical material in the ultrasonic probe.

ARL (Amplitude Reject Level) - The horizontal level on the cathode ray tube established by calibration. After calibration the ARL is 80% full screen height or 6 dB above the 40% line if a decibel attenuator is available.

Decibel (dB) - A logarithmic function of the ratio of two values. In ultrasonics the two values are the signal amplitude and a reference amplitude.

Decibel Attenuator - A gain control calibrated in decibels.

Delay Controls - An electronic means of horizontally shifting the pattern obtained on the cathode ray tube.

DRL (Disregard Level) - The horizontal level on the cathode ray tube established by calibration. After calibration the DRL is 40% of full screen height.

Frequency - The number of cycles in a unit of time. In ultrasonics the frequency is usually expressed Megahertz or MHz (million cycles per second).

Longitudinal Waves - A wave form in which the particle motion is essentially in the same direction as the wave propagation.

Megahertz (MHz) - A million cycles per second.

Pulse Echo - The sending of sound into a material in the form of spaced pulses and recording the length of time necessary for each pulse to travel through the medium and return to the source of energy.

RMS (Root Mean Square) - A type of average used in describing surface roughness.

Resulting Angle - The angle formed between the ultrasonic beam as it enters a medium of different characteristics than the one from which it came and a line drawn perpendicular to the interface between the two media.

Scanning Surface - The surface of the base metal where the ultrasonic probe is manipulated.

Search Unit - A transducer affixed to a suitable device to obtain the desired wave propagation.

Shear Wave - A wave form in which the particle motion is perpendicular to the direction of wave travel.

Straight Beam - A scan technique in which the sound beam is directed into the material perpendicular to the scan surface.

Transducer - A device for converting energy of one type into another. An ultrasonic transducer converts energy from electrical to mechanical and vice versa.

METRIC CONVERSION FACTORS

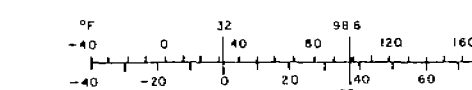
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	*fluid ounces*	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit *temperature*	5/9 (after *subtracting* 32)	Celsius *temperature*	°C

*1 in = 2.54 (exactly). For other exact conversions and more data tab tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Meas

Symbol	When You Know	Multiply by	To F
		LENGTH	
mm	millimeters	0.04	inc
cm	centimeters	0.4	inc
m	meters	3.3	fee
m	meters	1.1	yar
km	kilometers	0.6	mil
		AREA	
cm^2	square centimeters	0.16	squ
m^2	square meters	1.2	squ
km^2	square kilometers	0.4	squ
ha	hectares (10,000 m^2)	2.5	acr
		MASS (weight)	
g	grams	0.035	oun
kg	kilograms	2.2	pou
t	tonnes (1000 kg)	1.1	sho
		VOLUME	
ml	milliliters	0.03	flui
l	liters	2.1	pin
l	liters	1.06	qua
l	liters	0.26	gal
m^3	cubic meters	35	cub
m^3	cubic meters	1.3	cub
		TEMPERATURE (exact)	
°C	Celsius *temperature*	9/5 (then add 32)	Fahr



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13 ABSTRACT

A survey was made of various codes and standards applicable to the interpretation of nondestructive tests of welds in *ordinary-, medium-, and high-strength* low-alloy steels. This guide has been developed for application to steel welds in ship hull structures of the general cargo, tanker and passenger class as differentiated from naval ships. The guide exhibits nondestructive test results of several classes of defects with suitable test to delineate the maximum size and/or distribution that would be recommended as acceptable for ship hulls.

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