

Recommended Practice for Ultrasonic and Magnetic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Technicians

API RECOMMENDED PRACTICE 2X
FOURTH EDITION, APRIL 2004

REAFFIRMED, SEPTEMBER 2020



Recommended Practice for Ultrasonic and Magnetic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Technicians

Upstream Segment

API RECOMMENDED PRACTICE 2X
FOURTH EDITION, APRIL 2004

REAFFIRMED, SEPTEMBER 2020



SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Standards department telephone (202) 682-8000. A catalog of API publications, programs and services is published annually and updated biannually by API, and available through Global Engineering Documents, 15 Inverness Way East, M/S C303B, Englewood, CO 80112-5776.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the Director of the Standards department, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should be addressed to the Director, Business Services.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Copyright © 2004 American Petroleum Institute

FOREWORD

This recommended practice is under the jurisdiction of the API subcommittee on Offshore Structures.

Changes between this edition and the 3rd edition have been marked with “change bars” in the margin.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to API, Standards department, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

CONTENTS

	Page
1 SCOPE	1
2 REFERENCES	1
3 DEFINITIONS	1
4 PLANNING	2
5 QUALIFICATION OF PERSONNEL	2
5.1 General	2
5.2 Examination Prerequisites	3
5.3 Qualification Examinations	3
5.4 Reexamination	6
6 EXTENT OF NONDESTRUCTIVE EXAMINATION	6
6.1 Time of Examination	6
6.2 Examination During Onshore Fabrication	6
6.3 Examination During Offshore Installation	6
7 TECHNICAL RECOMMENDATIONS FOR UT	7
7.1 Applicability of Ultrasonic Examination to Offshore Structures	7
7.2 Advantages and Limitations of Ultrasonic Examination of Welds	7
7.3 Significance of Discontinuities	9
7.4 Procedure Qualification and Approval	9
7.5 Equipment	10
7.6 Preparation for Examination	16
7.7 Scanning Techniques	16
7.8 Discontinuity Location	21
7.9 Discontinuity Evaluation	27
7.10 Acceptance Criteria	33
7.11 Reporting	41
7.12 Verification	41
8 TECHNICAL RECOMMENDATIONS FOR MAGNETIC PARTICLE TESTING	42
8.1 Applicability of Magnetic Particle Examination to Offshore Structures	42
8.2 Advantages and Limitations	42
8.3 Procedure Qualification and Approval	42
8.4 Equipment	43
8.5 Examination Technique	45
8.6 Equipment Performance Checks (Standardization) and Evaluation of System Sensitivity	49
8.7 Interpretation and Evaluation of Indications	50
8.8 Acceptance Criteria	51
8.9 Reporting	51
APPENDIX A—EXAMPLE QUESTIONS FOR WRITTEN UT TEST	53
APPENDIX B—CONSTRUCTION AND UT EVALUATION OF MOCKUP STRUCTURES	57
APPENDIX C—EXAMPLE OF SCORING UT PERSONNEL PERFORMANCE ..	59
APPENDIX D—EXAMPLES OF UT AND MT REPORT FORMS	63

APPENDIX E—GLOSSARY OF NONDESTRUCTIVE EXAMINATION	
TERMINOLOGY	69
APPENDIX F—BIBLIOGRAPHY OF BACKGROUND REFERENCES	77

Figures

1—Weld Profiles Suitable for Preparation of Ultrasonic Test Plates	4
2—Method of Producing Incomplete Fusion “Defects” on Bevel Faces	5
3—Significance of Discontinuities.....	9
4—International Institutes of Welding (ITW) Ultrasonic Reference Blocks	13
5—Institute of Welding (IOW) Block	14
6—Check of Sweep Linearity	14
7—IIW Block—Determination of Angle Beam Transducer Index	14
8—IIW Block Showing Determination of Transducer Beam Angles	14
9—Determination of Beam Spread	15
10—Measurement of Beam Profile in the Vertical Plane	15
11—Measurement of Beam Spread in the Horizontal Plane.....	15
12—Weld Root Index	17
13—Weld Root Marking of Members for Installation Pile Splice Welds	18
14—Parameters Associated With Geometry of Pipe Intersection	19
15—Weld Root Examination.....	20
16—Scanning Patterns	20
17—Weld Scanning	21
18—Transfer Correction Determination	21
19—Graphical Plotting Cards Example 1	22
20—Graphical Plotting Cards Example 2	23
21—Graphical Plotting Cards Example 3	23
22—Graphical Plotting Cards Example 4	24
23—Graphical Plotting Cards Example 5	24
24—Graphical Plotting Cards Example 6	25
25—Graphical Plotting Cards Example 7	26
26—Graphical Plotting Cards Example 8	26
27—Circumferential Beam Path Scan.....	27
28—Skip Distance Adjustment for Circumferential Beam Path.....	28
29—Graphical Plotting Card for Circumferential Beam Path.....	29
30—Alternate Method for Determination of Skip Distance on Current Surfaces ...	30
31—Probe Manipulation for Spherical Discontinuity.....	30
32—Probe Manipulation for Planar Discontinuity.....	30
33—Distance Amplitude Correction	30
34—Beam Boundary Technique	31
35—Beam Boundary Plotting	32
36—Maximum Amplitude Technique	34
37—Multiple Reflectors	34
38—Circumferential Direction Beam Profile.....	34
39—20-Decibel d/B Beam Boundary Method	34
40—Length Measurement Comparison	34
41—Weld Profile Classifications.....	36
42—Design Curves for Different Weld Profiles Curve X From API RP 2A-WSD .	36
43—Reference for Level “A” Examination Block	37
44—Level A Acceptance Weld Quality.....	38
45—Internal Reflectors and All Other Welds	39
46—Reference for Level C Examination Block.....	40
47—Definitions	41
48—T, K, and Y Root Defects.....	42
49—Longitudinal Field Produced by Electromagnetic Yoke Setup.....	43

50—Radial Field Produced by “Single-Leg” Electromagnetic Setup	44
51—Magnetization Plan Setups	46
52—Illustration of API-Recommended Magnetic Field Indicator	46
53—Electromagnetic Yoke Setup for Detection of Longitudinal Discontinuities...	47
54—Electromagnetic Yoke Setup for Detection of Transverse Discontinuities	47
55—Incorrect and Correct Electromagnetic Yoke Setup for T and Y Joint Connections.....	48
56—Acceptable Setup for Scanning with “Single-Leg” Electromagnetic Method	48
57—Single-Leg Electromagnetic Setup for Detection of Longitudinal Discontinuities.....	48
A-1—Question 17 Diagram.....	54
A-2—Question 18 Diagram.....	54
A-3—Question 19 Diagram.....	55
B-1—Technique for Examining Welds Containing Natural Defects.....	58
C-1—Example of Key to Placement of Reflectors in Test Plate	60
C-2—Example of Typical Ultrasonic Technician Report of Test Results	61
C-3—Graphical Evaluation of Technician’s Report	62
D-1—Ultrasonic Examination Report Rejected Indications	66

Tables

1—Recommended Maximum Time Intervals Between Recalibration and Recertification of NDE Equipment	11
2—Recommended Standards and Maximum Performance Check Intervals for NDE and Mechanical Measuring Equipment.....	12
3—Transfer Correction Gain Adjustment	21

Recommended Practice for Ultrasonic and Magnetic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Technicians

1 Scope

This recommended practice (RP) for nondestructive examination (NDE) of offshore structural fabrication and guidelines for qualification of personnel contains guidance on NDE methods which have evolved from fabrication experience with offshore structures. These methods are commonly used and have found acceptance due to their reliable detection of discontinuities. The five NDE methods routinely used in offshore structural fabrication are visual (VT), penetrant (PT), magnetic particle (MT), radiography (RT), and ultrasonic (UT) examinations. This recommended practice primarily addresses the MT and UT methods. Guidance on VT, PT and RT is incorporated by reference to ANSI/AWS D1.1. Further recommendations are offered for determining the qualifications of personnel using MT and UT techniques. Recommendations are also offered for the integration of these techniques into a general quality control program. The interrelationship between joint design, the significance of defects in welds, and the ability of NDE personnel to detect critical-size defects is also discussed.

THIS DOCUMENT IS NEITHER A CODE NOR A SPECIFICATION AND SHOULD NOT BE UTILIZED AS SUCH BY THE OPERATOR.

2 References

The applicable editions of non-API standards referenced herein are as follows. Only the latest editions of these standards should be considered applicable, unless otherwise stated.

API

- RP 2A-LRFD *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms—Load and Resistance Factor Design*
- RP 2A-WSD *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms Working Stress Design*

ANSI¹/AWS²

- A3.0 *Standard Welding Terms and Definitions*
- D1.1 *Structural Welding Code—Steel*
- B1.10 *Guide for the Nondestructive Inspection of Welds*
- B1.11 *Guide for the Visual Inspection of Welds*

¹American National Standards Institute, 11 West 42nd Street, New York, New York 10036.

²American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33135.

ASNT³

- SNT-TC-1A *Recommended Practice for Qualification and Certification of NDE Personnel*

ASTM⁴

- A 435/A 435M *Straight-Beam Ultrasonic Examination of Steel Plates*
- A 578/A 578M *Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications*
- E 587 *Standard Practice for Ultrasonic Angle-Beam Examination by the Contact Method*
- E 709 *Standard Guide for Magnetic Particle Examination*
- E 1444 *Standard Practice for Magnetic Particle Examination*

3 Definitions

The welding terminology used herein is defined in the American Welding Society publication A3.0. Relevant ultrasonic terminology is defined in the Glossary section, Appendix E, of this document. Other definitions of interest are tabulated in the following. For the purpose of this standard, the following definitions apply:

3.1 acceptance criteria: Limit of shape, size, and position of discontinuities acceptable within the context of the specific design requirements.

3.2 agency personnel: Personnel employed and trained by an independent organization, offered to the Operator on a contract basis, for assisting in the construction inspection.

3.3 certification: Written testimony of qualification.

3.4 designer: The person, firm, corporation, or other organization employed by the Operator during fabrication and installation with responsibility for examining all details of fabrication to ensure compliance with construction specifications.

3.5 inspector: The individual representing the Operator during fabrication and installation with responsibility for examining all details of fabrication to ensure compliance with construction specifications.

3.6 NDE examination: An examination of materials and fabrication by qualified personnel responsible to the inspector using equipment for the purpose of locating and sizing discontinuities in materials or welds and reporting

³American Society of Nondestructive Testing, Inc., 1711 Arlington Lane, P.O. Box 28518, Columbus, Ohio 43228-0518, www.asnt.org.

⁴ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, www.astm.org.

such findings to the inspector for evaluation of compliance with the acceptance criteria.

3.7 NDE examination procedure: The detailed written procedure outlining the specific examination techniques and criteria to be utilized during the construction of a particular structure.

3.8 NDE specialist: An individual with extensive experience in the preparation and application of nondestructive examination procedures. Typically an individual classified by the American Society for Nondestructive Testing as a Level III or equivalent. An NDE specialist may be certified in one or more NDE methods (that is, MT, UT, RT, and so forth).

3.9 operator: The person, firm, corporation, or other organization employed by the owner to oversee the construction and/or operation of the facility.

3.10 qualification: Demonstrated skill and knowledge and documented training and experience required for personnel to properly perform the duties of a specific job.

4 Planning

4.1 These recommendations are intended to serve as guidelines for establishing a controlled program of nondestructive examination by magnetic particle and ultrasonic methods during fabrication and installation of offshore facilities. They are intended to be used in the context of a comprehensive fracture control plan that includes design philosophy and material selection as well as NDE. IT IS INTENDED THAT THE OPERATOR'S NDE SPECIALIST DEVELOP DETAILED PROCEDURES FOR EXAMINATION. THESE DETAILED PROCEDURES SHOULD DRAW ON THE TECHNICAL GUIDANCE IN SECTIONS 7 AND 8, TOGETHER WITH PERSONNEL QUALIFICATIONS AS DESCRIBED IN SECTION 5, WHICH SHOULD PROVIDE THE TECHNICAL BASIS FOR A NONDESTRUCTIVE EXAMINATION PROGRAM.

4.2 These recommendations assume that the design of the structure is performed in accordance with the API Recommended Practices 2A-WSD or 2A-LRFD. The operator and the designer should recognize the potential that undetected flaws may exist in the structure even after inspection and examination by qualified personnel. In establishing NDE requirements, consideration should be given to the ease or difficulty of successful joining of specific details, accessibility by other examination methods, feasibility of repair, and the significance of a failure to structural integrity. Both the extent of the examination and the acceptance criteria are closely related to these issues.

4.3 Typical applications of NDE and the extent of coverage of particular fabrication details are given in Table 13.4.3 of API Recommended Practice 2A-WSD. Some of the details listed are inspected by complementary methods. When this occurs, the advantages (confidence, convenience, and the like) of each method should be carefully weighed to determine which is most appropriate. Utilizing more than one

method of NDE may often result in more reliable and better defined results than using a single examination method.

4.4 The use of magnetic particle techniques by the offshore fabrication industry provides an efficient method of detecting surface and near-surface breaking discontinuities. The MT technique described in Section 8 and performed by qualified MT personnel provides the operator with a high confidence level that relevant indications will be detected and false alarms minimized.

4.5 The use of ultrasonic examination techniques by the offshore industry results from an inaccessibility of some fabrication details (particularly T, K, and Y connections in tubular trusses) by any other examination method capable of evaluating the full cross section of the connection. Limited to this singular method, the operator and designer should recognize the inherent limitations of the ultrasonic technique for weld examination. Some of the more significant limitations are detailed in the technical discussions in Section 7.

4.6 Due to the inherent limitations of nondestructive examination of welded joints, the following quality assurance measures are suggested for incorporation into the overall quality control program:

- Qualification of all welders and welding procedures to be employed in fabrication, especially for tubular member connections.
- Complete visual inspection (VT) before, during and after welding as more fully described in ANSI/AWS B1.11 (latest edition), *Guide for the Visual Inspection of Welds*, VT of the fit-up of designated critical welds should include recording of the joint geometry.

5 Qualification of Personnel

5.1 GENERAL

5.1.1 The following paragraphs offer a guide for qualifying personnel to be employed in NDE of materials and fabrication during the construction of offshore platforms. These recommendations are intended to guide the operator in determining the proficiency of NDE personnel in the examination of weld joint configurations and fabrication details which are unique in the construction of offshore platforms.

5.1.2 NDE personnel performing evaluation of examination results should be certified to level II in accordance with ASNT SNT-TC-1A or approved equivalent in the techniques used for NDE in this document. Trainees and Level I personnel should be allowed to assist or conduct examinations under constant direction and supervision of the qualified personnel.

Personnel responsible for performing ultrasonic examinations of welded tubular structures should be thoroughly familiar with pulse-echo shear wave ultrasonic equipment and the techniques of evaluation from curved surfaces with minimum surface preparation where only one surface is accessible. They should be specifically trained to accurately locate ultrasonic reflectors using the triangulation technique, and to eval-

uate discontinuity size, using amplitude and beam boundary techniques. They should be trained and experienced in measuring effective beam angles, beam profiles, applying transfer mechanisms, and effecting distance amplitude corrections.

5.1.3 The operator should require personnel to demonstrate proficiency by satisfactory performance in a pre-qualification examination. The examination should consist of both written and practical tests which have been developed by the agency's NDE specialist, or an organization approved by the operator, and should incorporate the specific requirements of the NDE procedure and the acceptance standards contained in Sections 7.10 and 8.8 as applicable. The examination may also include a review of the candidates qualification and certification records with the Agency.

5.2 EXAMINATION PREREQUISITES

Applicants for API RP 2X qualification to perform NDE for the Operator should possess at least the following qualifications:

- a. Certification in General Specific and Practical NDE to Level II as defined in 5.12 which is traceable to a nationally or internationally recognized certification program.
- b. Accumulation of experience in NDE of tubular members (as described in this RP) prior to examination as follows:

1. Ultrasonic—400 hours.
2. Magnetic particle—200 hours.

- c. Visual Acuity Test. All candidates for examination should be subjected to an eye examination or furnish proof of a recent examination by competent medical authority to prove a natural or corrected near vision acuity for reading J-1 letters on Jaeger's standard test chart at a distance of not less than 12 inches and a natural or corrected distance acuity of not less than 20/40.

All personnel accepted for employment should be reexamined for visual acuity at least once a year and corrective measures employed to maintain acuity within the preceding stated limits.

5.3 QUALIFICATION EXAMINATIONS

5.3.1 Tests

Both written and practical tests should be administered to ensure the candidate understands the principles and techniques of the NDE methods used in the examination of tubular members. The candidate should also demonstrate his or her ability to detect and evaluate discontinuities in representative weldment samples.

5.3.2 Written Test

The written test should evaluate the candidate's knowledge of basic principles and the ability to apply them to field operations. The topics covered should include:

- a. Magnetic particle examination: Magnetizing methods, magnetic field measurement techniques, calibration and use of devices such as Hall-effect gauss (tesla) meters, particle application and removal, false indications and defect removal and the acceptance criteria specified in 8.8.

- b. Ultrasonic examination: Probe selection, equipment calibration and standardization, attenuation, discontinuity location, discontinuity sizing, defect removal, and the acceptance criteria specified in 7.10.

The general part of the test should contain questions on fabrication and welding. The mathematics associated with the test procedures should be consistent with the requirements of field calculations. Tests should contain multiple choice, true/false and essay questions, as well as problem exercises on flaw location and sizing. Examples of written UT test questions are included in Appendix A. (Note: the test questions are examples to be used as guidance and should not be extracted directly from Appendix A.)

The written test is intended to further screen applicants for the practical examination. The minimum acceptable score on the written test should be 80 percent.

5.3.3 Practical Test

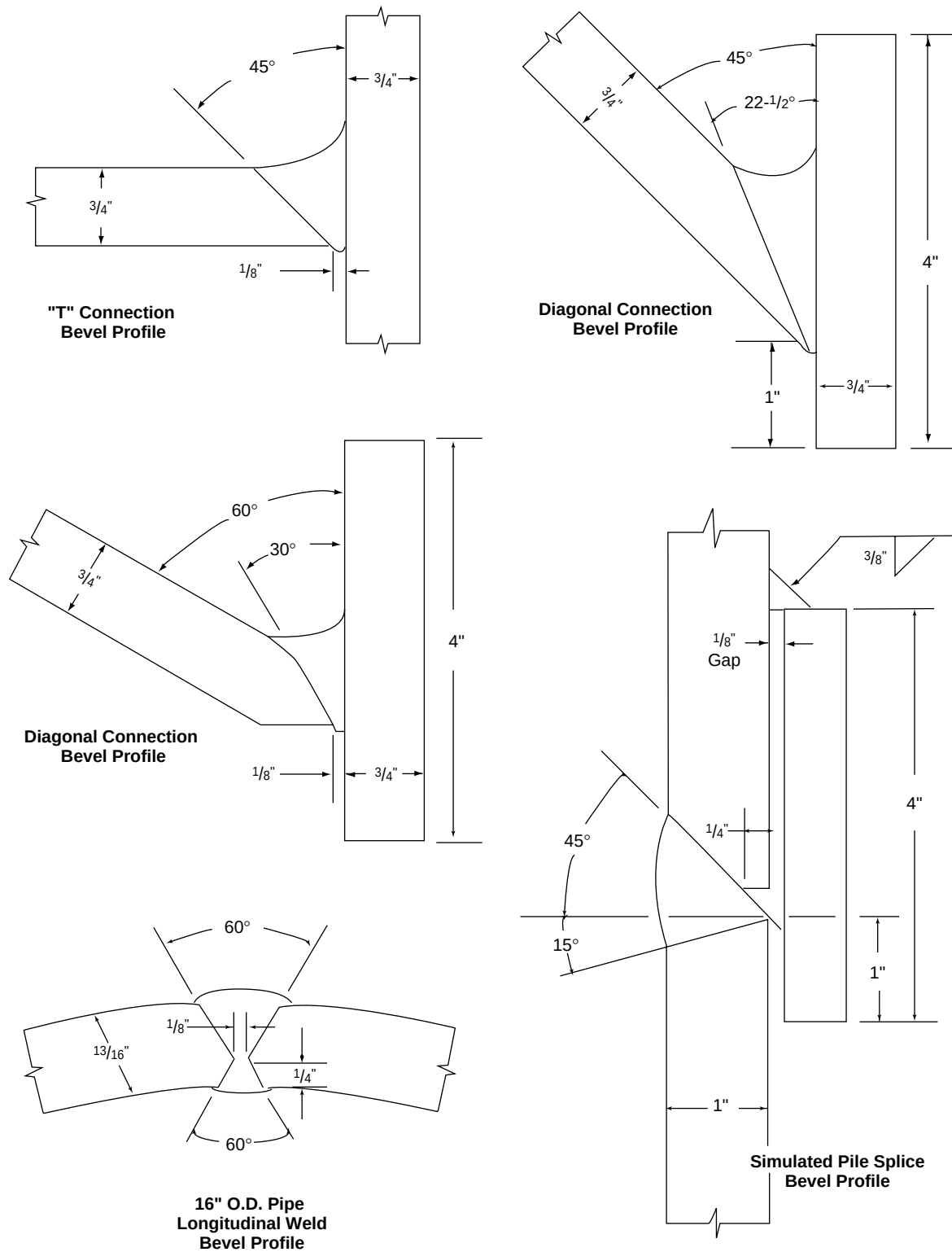
The practical test determines the candidate's ability to detect and evaluate weld discontinuities of interest. Demonstration of such ability is the object of the qualification examination and should be considered of greater significance than all other requirements.

The operator is responsible for having test coupons prepared that are of the type and number required to represent the details of actual structural fabrication. Suitable test pieces may be full mock-ups of tubular joints or flat plate connections which simulate typical cross sections. Three or four different test plates, 18 to 24 inches in length, with typical joint configurations and a total of ten or more "defects" should provide an adequate test of ability. See Figure 1 for joint designs employed in past evaluation programs.

The practical examination should also test the ability of NDE personnel to correctly complete the relevant paperwork associated with reporting procedures for NDE.

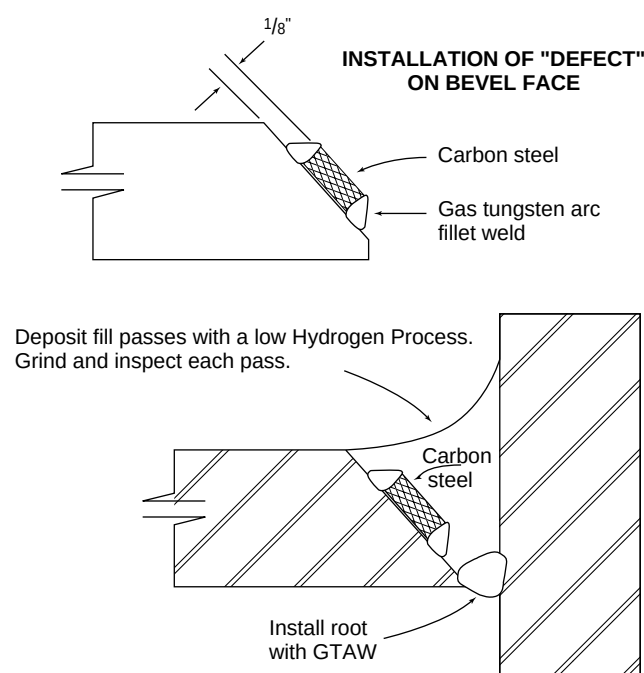
Test coupons may contain natural discontinuities or artificial reflectors consisting of non-metallic inserts in the weld deposit, slots or holes machined in the weld, or thin steel inserts fillet welded to bevel preparations to simulate incomplete fusion. See Figure 2 for details. Mock-up structures will generally contain sufficient natural discontinuities to test the candidate's ability; however, placement of additional artificial reflectors in critical areas may be desired to access any limitations of the candidate's technique. See Appendix B for additional details on mock-up structure fabrication and evaluation.

Test coupons to be employed in repetitive examinations should be fabricated to produce intentional reflectors and to minimize natural flaws. These test pieces should subsequently be examined by an ultrasonic specialist to confirm the detectability of the implant and the absence of unintentional reflectors. The ultrasonic specialist should characterize each reflector in the test plates into one of the categories defined herein. The characterization, size, and placement of the reflectors may then be discussed with the candidate following completion of the examination. If the test pieces are to be



Note: The width of the plate from which scanning is to be allowed should be eight inches or more.

Figure 1—Weld Profiles Suitable for Preparation of Ultrasonic Test Plates



Note: The width of the plate from which scanning is to be allowed should be eight inches or more.

Figure 2—Method of Producing Incomplete Fusion "Defects" on Bevel Faces

used for late examinations, the examiner should be cautious of revealing the exact details of the individual test pieces to avoid compromising the results of the subsequent examinations.

All materials to be employed for test coupon fabrication should be examined by longitudinal wave techniques to ensure the absence of lamination and/or inclusions which might render the test pieces unacceptable for test purposes. Conversely, such materials may intentionally be incorporated into selected coupons to evaluate the candidate's performance on these imperfections. Weld test pieces which result in framing one plate or tubular onto the surface of another plate or tubular should be produced from steels with enhanced through-thickness properties to minimize lamellar tearing within the test coupon.

The reflectivity of natural and artificial planar discontinuities is influenced by residual compressive welding stresses. A thermal stress relief or full normalizing heat treatment should be required to ensure that the reflecting surface is representative of the actual discontinuity dimensions. Smooth planar reflectors acted upon by sufficient compressive stress will not be detected by ultrasonic examination but can be readily seen upon sectioning or nick-fracture tests.

The size of discontinuities inserted or induced into the test coupons should be consistent with the range of flaw size acceptance criteria set forth in this document.

5.3.4 Scoring

Candidates shall submit a written report of all detected discontinuities found during the test piece examination. The report shall include the following information as applicable to the test method:

- MT—Length, location on cap surface, and location along weld (from Y).
- UT—Type (spherical, cylindrical, or planar), size (length and width), location along the weld, and position within the well cross section.

The report should be used in compiling a performance score. The performance rating are established by the following formulas:

$$P = \frac{L_c}{L_a} \times 100 \quad \text{Formula 1}$$

$$R = \left(\frac{L_c}{L_i} \right) \left(1 - \frac{L_f}{L_i} \right) \times 100 \quad \text{Formula 2}$$

Where:

- P = percentage of actual reflectors correctly detected and sized.
- R = overall rating including penalty for false alarms, 0 to 100.
- L_a = length of actual reflector contained in the coupon.
- L_c = indicated length of actual discontinuities that have been correctly sized and located. (Credit is given for the lesser of the reported length or actual length of the reflector).
- L_i = total length of call by the candidate, right or wrong.
- L_f = length of call to where discontinuity exists.

Each linear inch of test-piece weld should be considered independently in the compilation of the candidate's performance. Identification of the discontinuity should be considered correct when the size and location of the reflector have been determined with sufficient accuracy to rate the discontinuity in accordance with the acceptance criteria. For ultrasonic examination with dimensions indicated within a factor of two of true dimensions in other words, one-half to twice the actual dimension should be considered accurate within the limits of the examination technique.

Formula 1 indicates the ability of the candidate to locate and size discontinuities that exist in the test pieces. A candidate should achieve a score of 70 or above on Formula 1 is suggested as a minimum performance.

Formula 2 indicates the ability of the candidate to accept the areas of welds in the test pieces where no flaws exist. A low score indicates the candidate may call for a large number of unnecessary repairs during the course of the actual

construction work. The operator should consider, in evaluating the required performance, the consequences of unnecessary repairs, including the fact that weld repairs are made under less-favorable conditions than the original weld, thereby increasing the potential for a defective repair weld. Consequently, a score of 50 or above on Formula 2 is suggested as a minimum performance.

Examples of test pieces, test report forms, sample results, and sample grading evaluations are included in Appendix C.

5.4 REEXAMINATION

Previously qualified personnel should be reexamined when they have not performed nondestructive examination of tubular member construction for a period not to exceed 1 year, or when a specific cause to question performance arises, or more frequently as required by the operator.

6 Extent of Nondestructive Examination

6.1 TIME OF EXAMINATION

All NDE should be performed at a suitable interval after welds have been completed and cooled to ambient temperature. The interval can range from immediately upon cooling up to 72 hours depending on the grade of steel. Some high-strength steels (60,000 ksi yield and greater) require a minimum interval of 48 to 72 hours due to the possibility of delayed cracking. The operator should approve the interval for all examinations.

The nature of offshore installation usually requires operations to be completed in as timely a manner as possible. This may result in a need to begin the UT of pile splice welds before they have cooled to ambient temperature. Elevated temperatures of materials may change sound beam characteristics and should be explored prior to accepting Agency procedures. The operator should approve such an examination and insure the Agency has a qualified procedure that is applicable to this situation.

6.2 EXAMINATION DURING ONSHORE FABRICATION

Wherever possible, examination, repair, and reexamination should be accomplished in the earliest stage of fabrication and before incorporation into the structure. Examination which can be effectively accomplished in the fabrication yard should not be delayed until offshore installation.

6.2.1 Examination of Plate for Structural Members

6.2.1.1 Lamination and inclusions in plate employed for chord members at tubular joint connections often result in separations within the plate thickness when subjected to the strains of welding. Separations which develop by fracture between adjacent discontinuous inclusions are termed *lamellar tearing*. Similar problems exist in the fabrication

of plate girders where the web and stiffener connections impose welding-contraction strains. The ultrasonic examination technique is capable of detecting pre-existing lamination and major inclusions which may add to these difficulties during fabrication.

6.2.1.2 Plate to be employed as chord members at tubular connections (joint cans at nodes) and for the flanges of critical girders requiring substantial stiffening may be ultrasonically examined at the steel mill, prior to purchase, in accordance with ASTM Specifications A 435 or A 578, Level II. These specifications, which are essentially the same, require that only those plates with major flaws that result in the complete loss of sound energy (in other words, plates with lamination) are rejected. Some indication of the suitability of critical application plate may be determined by implementing ASTM A 578, Level II criteria which require additional reporting of some inclusions less than three inches in length. The A 578, Level I, criteria require the additional reporting of major inclusions; however, this specification may impose special processing at the steel mill and add to the cost of the plate.

A fabrication yard examination or reexamination of plates subjected to mill ultrasonic examination is desirable to further define quality in the areas of projected intersection. The areas of framing should be examined 100 percent along and on either side of the projected line of intersection. Plates or tubulars found to contain ultrasonic indications should be relocated in the structure or repositioned in the same location to minimize the concentration of imperfections in the projected weld area. Freedom from all ultrasonic indications in a band at least six inches wide is desirable, but any imperfection which cannot be eliminated from the weld area should be carefully measured as a basis for re-evaluation after completion of welding. Despite the most stringent ultrasonic examination, these measures will not ensure freedom from microscopic inclusion arrays which can subsequently cause lamellar tearing. With increasing plate thickness above one inches, and complex joint designs, it may be desirable to employ plate specially processed at the steel mill to ensure freedom from the tearing problem.

6.2.2 Type and Extent of Examination

The recommended type and extent of NDE during onshore fabrication is given in Table 13.4.3, in API RP 2A-WSD.

6.3 EXAMINATION DURING OFFSHORE INSTALLATION

The difficult conditions of offshore work result in an increased (not a decreased) need for nondestructive examination. The advantages of the ultrasonic technique over radiography for offshore installation examinations are an increase in the examination rate in heavy sections and a reduction in radiation hazard in the confined working spaces.

7 Technical Recommendations for UT

7.1 APPLICABILITY OF ULTRASONIC EXAMINATION TO OFFSHORE STRUCTURES

7.1.1 Offshore structures require extensive use of T, K, and Y tubular member intersections and ring and diaphragm-stiffened tubulars. Considering the limitations of alternate methods, ultrasonic examination is recommended for the detection of internal discontinuities.

7.1.2 Other connections common to deck fabrication such as plate girder, beam shape, box and plate connections, and tubular-beam intersections may be suited to either RT or UT as local geometry dictates.

7.2 ADVANTAGES AND LIMITATIONS OF ULTRASONIC EXAMINATION OF WELDS

As with all examination methods, the ultrasonic technique has numerous advantages and some serious limitations. Among others, limitations include the absence of permanent records, such as those provided by radiography, and a heavy dependence on the skill and training of personnel. A knowledge of these limitations and the cause of the occasional technician error are a necessity in formulating a comprehensive examination program. This section defines the major attributes and limitations of the ultrasonic technique.

7.2.1 Comparison with Radiography

7.2.1.2 History

Historically, ultrasonic technique has been and will continue to be compared to radiographic examination even though these methods of examination differ significantly as to the types of flaws detected and the ability of personnel to evaluate the flaw. In the comparisons to follow, the functions of detection and evaluation are considered separately to permit an equitable assessment of each method's attributes and limitations.

7.2.1.3 Detection

Radiography is most sensitive to three-dimensional discontinuities, such as lack-of-penetration, slag inclusions, and porosity. Other discontinuities, such as cracks and lack-of-fusion, are less reliably detected, especially when oriented askew of the radiation beam. In order to be readily discernible on the film, the thickness of the discontinuity parallel to the radiation beam must be on the order of two percent of the weld thickness. As the thickness of the weld increases, the quality of the discontinuity image decreases due to radiation scattering within the weld.

In contrast to radiography, the ultrasonic technique is highly sensitive to two-dimensional discontinuities and less sensitive to three-dimensional ones. Tight cracks and lack-of-fusion discontinuities are also difficult to detect with

ultrasonics; however, the threshold limit for the ultrasonic technique is considerably smaller than for radiography. Not infrequently, cracks and similar discontinuities in areas of high comprehensive-residual weld stress are so tight that they are completely invisible to ultrasonics. In most cases, this limitation should not be cause for great alarm since the more common fracture mechanisms are dependent on tensile, not compressive, stress fields. However, welds subjected to stress relief treatment prior to entering service should be examined after stress relief.

After limitation in the use of shear wave ultrasonic inspection is the failure to detect large two-dimensional (planar) discontinuities as a result of the inherent direction of the reflected beam. Large flat discontinuities reflect the acoustical energy away from the receiving transducer and therefore often go undetected in single-angle or single-transducer examination. Conversely, small discontinuities produce a scattering of reflected energy over a broad angular envelope, increasing the chance of detection.

The direction of the ultrasonic beam also causes difficulty in detection of certain types of discontinuities. For example, single pores or randomly dispersed porosity is particularly difficult, if not impossible, to detect at sensitivities recommended for the detection of planar discontinuities significant to service performance. Spherical discontinuities (and to a lesser extent those of cylindrical shape) have only a fraction of their area perpendicular to the acoustic beam and therefore do not return acoustical energy proportional to their physical size.

7.2.1.4 Evaluation

Evaluation implies the identification and sizing of detected discontinuities since some discontinuities, such as porosity and isolated slag, are of little significance in most fracture-control plans. It is worthwhile to identify the character and source of each anomaly, not only to effect removal of those of rejectable size but also to permit preventive corrective action. Of the two methods, radiography is the better tool for identification. Conversely, the information yielded by ultrasonic instrumentation is only a portion of that required for identification. To reach a reasonable conclusion as to indication type, qualified UT personnel must be thoroughly familiar with the welding process and the degree of perfection in fit-up, and have accurately located the reflector within the weld profile. Combining this information with that obtained by secondary manipulations of probe angle and beam, qualified UT personnel are able to reliably identify only three geometric discontinuity configurations with spherical, cylindrical, and planar. The technique is inherently incapable of differentiation between such discontinuities as lack-of-fusion at the root and incomplete penetration or, more importantly, the coincidental presence of cracks radiating from these fusion defects.



Documents

Document Sharing Hub

For most construction programs, such fine definitions of discontinuity characters are probably unnecessary if qualified UT personnel can reliably separate two-dimensional planar discontinuities from the others, because the planar discontinuities are more critical to the fracture phenomenon.

Identification without sizing is of little value to an engineered fracture-control program. In sizing, the usefulness of radiography must be limited to assessing the projected discontinuity length. Even though radiographic techniques exist for assessing the other dimensions, the position, and orientation within weld profile, these are not readily adaptable to fabrication yard usage.

Before discussing any attributes for ultrasonic discontinuity size measurement, it is worthwhile to consider the techniques available and the limitations of each. Two techniques are commonly practiced, each with its own advantages. The first, called *amplitude measurement*, is rather simple and particularly suited to measuring discontinuities of small size that can be completely contained within the cross section of the ultrasonic beam. Accuracy of the technique deteriorates rapidly as discontinuities increase in size and approaches a limit of applicability when the discontinuity exceeds $1/4$ inch (6 millimeters). The major disadvantage of the technique lies in the fact that the total reflecting area is responsible for the echo height, rendering it impossible to differentiate between length and width of the reflector.

The second, called *beam boundary intercept* technique, offers greater advantage in determining both the length and width of most discontinuities of significance. Theoretically, the technique is accurate when used properly. However, the unavoidable variations in probe characteristics plus the requirements for precalibration of equipment and the need for exceptionally skilled personnel somewhat diminish the accuracy of results. Also, the technique becomes more complicated as the thickness of the weld decreases. Regardless of painstaking laborious efforts to minimize the influence, the technique accuracy tolerance on width is seldom better than $\pm 1/16$ inch (1.6 millimeters).

7.2.2 Influence by Different Types of Welds

7.2.2.1 Ultrasonic techniques become more reliable on full penetration butt welds in pipe and plate in thicknesses over $1/2$ inch (12.5 millimeters). Weld geometry in the T, K, and Y configurations results in only slight degradation in the ability to perform meaningful examinations. Welds that have been ground flush with the base metal, those deposited from two sides, and the single-sided weld are preferred in that order for optimum examination results.

7.2.2.2 Partial penetration welds are next in difficulty. The inaccuracies inherent in measuring the extent of the unfused boundary at the root are the same as for the measurement of any other discontinuity. More important is the inability of the method to differentiate the presence of a

crack at the terminus of the first weld bead from the intentional or permissible unfused boundary.

7.2.2.3 Ultrasonic inspection of fillet welds yields questionable results, particularly in sections of thin to medium thickness. Applications where the fillet weld is sufficient in size to contain the entire beam are few, and fewer still are those fillet weld configurations where potential discontinuity orientations can be intercepted at the optimum incident angles. When a fillet-weld detail is considered structurally critical, it is generally wise to employ alternate or supplementary means of examination.

7.2.3 Influence of Section Thickness

The utility of the ultrasonic method in this respect is opposite that of radiography. Radiography (with proper choice of radiation source) yields more reliable results at less expense in thinner sections. Conversely, ultrasonic weld examinations on thin-section welds are performed with great difficulty. Reflections from the root and weld crown are difficult to separate from the detrimental weld discontinuities, and flaw sizing is generally restricted to the amplitude technique. For full-penetration butt welds below thicknesses of 1 inch (25 millimeters), a comparison of efficiency and cost to produce equivalent information favors the radiographic technique. As the thickness increases, the utility of the ultrasonic method becomes more apparent.

7.2.4 Influence of Material Properties

Some steel manufacturing processes, such as control rolled and thermo-mechanical controlled process (TMCP) steels, can cause minor variations in acoustic properties. This effect on velocity may cause changes to the transducer beam angle in comparison to the reference standard.

7.2.5 Influence of External Factors

7.2.5.1 The physical condition of the weld and base metal significantly influences the detection and evaluation of weld flaws. Surface conditioning and the acoustical characteristics of the base metal will determine the amount of sound lost through scattering and absorption prior to interception with the weld discontinuity. Inclusions and lamination in the base metal will misdirect shear wave beams away from intended areas of examination and produce reflections from unknown and unidentified areas.

7.2.5.2 Ambient temperature is not a particularly troublesome influence on the ultrasonic examination, although some early models of miniaturized instrumentation ceased to operate at low temperatures. Low temperatures reduce the suitability of available coupling agents.

High environmental temperatures do not normally influence instrument performance as UT personnel generally

cannot work at elevated temperatures that are below those that affect the instrument. Elevated base-metal temperatures, however, do significantly influence the examination results. Aside from creating a coupling problem, elevated base-metal temperatures increase the velocity of the sound wave propagation resulting in a change in shear wave incidence angle and an inaccuracy in reflector locations unless all calibrations are performed at the same temperature as the detail to be inspected. Through application of high-temperature couplants and proper calibration corrections, it is possible to perform useful examinations on uniformly heated materials. Conversely, examinations conducted immediately following deposition of a weld when inherent thermal gradients of unknown magnitude exist yield questionable results.

7.2.5.3 The performance of ultrasonic examinations in bright sunlight without benefit of cathode ray tube shading imposes a serious limitation on UT personnel and the examination results. Transitory cathode ray tube indications are often missed under the best of circumstances; therefore, protective shading should be a mandatory equipment requirement for all ultrasonic examinations.

7.3 SIGNIFICANCE OF DISCONTINUITIES

All welds contain some discontinuities which can be detected by the ultrasonic examination method if sufficient instrumentation sensitivity is employed. To decide whether or not these constitute defects which must be repaired requires the intelligent application of acceptance criteria. In many codes, arbitrary acceptance criteria are specified to cover all cases; these often correspond to reasonably attainable workmanship standards for relatively innocuous discontinuities, such as porosity and minor slag inclusions, which show up prominently in traditional radiographic examinations. A more recent development is the fitness-for-purpose approach, which attempts to set acceptance criteria at the level where discontinuities begin to adversely affect weld performance, including a safety factor for the inaccuracies of examination. The typical relationship of fitness-for-purpose criteria to traditional workmanship standards is shown in Figure 3. A comprehensive fitness-for-purpose approach may produce different acceptance criteria for different applications, as the critical flaw size may be dependent upon fracture toughness, strength, fatigue and corrosion-fatigue performance, cyclic and maximum stress levels, postweld heat treatment, and component geometries. Finally, there may be cases where accepting some loss in performance is justified by the economics of expensive repairs versus marginal improvement, or the risk that an attempted repair (made under less favorable conditions than the original weld) will lead to undetected flaws worse than the original. Thus, there is nothing inconsistent with an operator purchasing a platform to the more restrictive workmanship guidelines, then subsequently choosing to analyze

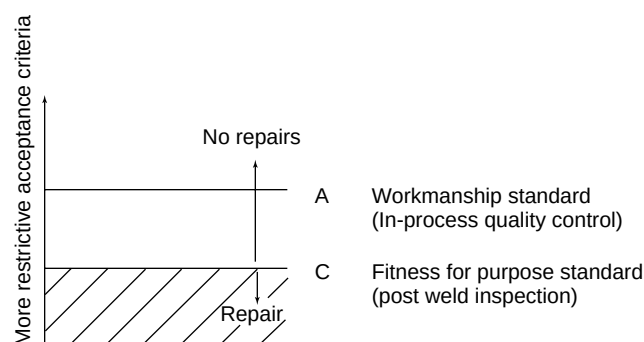


Figure 3—Significance of Discontinuities

postacceptance or in-service flaws on a fitness-for-purpose basis. However, this approach should not be used to relieve the fabricator from delivering the level of quality that was contracted for, or to excuse poor performance after the fact. The operator should establish an acceptance criteria for each structure in consultation with the design organization and the ultrasonic specialist. See 7.10 for examples of acceptance criteria.

7.4 PROCEDURE QUALIFICATION AND APPROVAL

The following applies to procedure qualification and approval:

- a. Written ultrasonic examination procedures should be prepared by the ultrasonic specialist, proven by practical tests of the type used for qualification of personnel, and approved by the operator, and should continue in force until cause is shown to question the validity of the procedure.
- b. The following list of essential variables should be detailed in the written procedure and employed during trial and subsequent weld examinations. Significant variations from the proven procedure should be cause for requalification.
 1. Type of weld configurations and surface temperature range to be examined.
 2. Acceptance criteria for each type of weld.
 3. Type of ultrasonic instrumentation (manufacturer, model, and serial number).
 4. Use of electronic gates, suppression, alarms, and the like.
 5. Equipment calibration and frequency.
 6. Equipment standardization and frequency.
 7. Length of coaxial cable.
 8. Transducer frequency, size and shape, beam angle, and type of wedge on angle beam probes.
 9. Surface preparation.
 10. Couplant.
 11. Base metal examination.
 12. Transfer correction.
 13. Scanning sensitivity.
 14. Scanning pattern.
 15. Triangulation methods for determining effective

- beam angle, indexing of root area, and flaw location.
- 16. Method of discontinuity length determination.
- 17. Method of discontinuity width determination.
- 18. Computer hardware and software used for locating and sizing reflectors.
- 19. Reporting and retention.

7.5 EQUIPMENT

The success of any ultrasonic examination is strongly dependent on the accuracy and performance of the electronic equipment and the auxiliary devices required to calibrate the equipment and evaluate the examination results. The following paragraphs outline the desired equipment performance, recommended calibration standards, and methods of assessing equipment performance. A recommended minimum inventory of equipment to be available to UT personnel is also included.

7.5.1 Electronic Instrumentation

The following apply to electronic instrumentation:

- a. All examinations should be conducted with an ultrasonic pulse-echo system capable of excitation frequencies between one and ten megahertz. The instrument should have facility for both single and dual transducer operation with one element acting as transmitter and the second as receiver. Information should be presented on an A-scan cathode ray tube. Instrumentation for field and yard usage should be powered by internal or auxiliary batteries capable of eight hours continuous usage.
- b. Concerning minimum sensitivity, each instrument-transducer combination should be capable of producing a minimum $\frac{3}{4}$ CRT vertical scale echo signal from the 4-inch (100 millimeter) radius curved surface of the International Institute of Welding calibration standard with a minimum of 40 decibels amplification in reserve.
- c. The system should provide a horizontal sweep with a linearity within 1 percent of the full screen or CRT grid overlay range.
- d. The instrument should have a calibrated gain control electrically accurate to within one 1 decibel over a range of not less than 60 decibels. Adjustments should be possible in increments no larger than 2 decibels/step.
- e. Systems operated from line or external power sources should be provided with voltage stabilization to maintain fluctuations within plus or minus 2 volts for an external fluctuation from 90 volts to 130 volts.
- f. Transducer elements should oscillate at a frequency between 1 and 6 megahertz (MHz) and be free of noise and internal reflections which produce CRT reflections exceeding 5 percent of the vertical scale height at the working sensitivity employed for weld examinations. Each transducer should be clearly marked to identify frequency, plus sound incident angle and index point when applicable.

7.5.2 Equipment Requirements

The following list of UT instrumentation, calibration standards, and auxiliary equipment is considered the minimum necessary for ultrasonic weld examination:

- a. An ultrasonic pulse-echo instrument meeting the requirements of this section.
- b. At least one longitudinal (compressional) wave transducer, $\frac{1}{2}$ inch to 1 inch (12.5 millimeters to 25 millimeters) in diameter, of a nominal frequency of 2.25 megahertz.
- c. One each of nominal 45, 60, and 70-degree angle beam transducers of a nominal frequency of 2 megahertz to 2.25 megahertz. The oscillating element should be approximately square or round in shape with dimensions which result in an included beam angle of approximately 15 degrees at 6 decibels less than the centerline maximum.
- d. An additional set of carefully selected and calibrated angle beam transducers for reflector evaluation. High-frequency transducers are recommended.
- e. Two coaxial cables, 6 feet (2 meters) or more in length.
- f. One IIW calibration standard for standardizing instrument performance as outlined in this section.
- g. Angle beam distance calibration standards for office and field calibrations, in other words, IIW, DSC, or DC.
- h. One IOW calibration standard for evaluation of beam profiles as outlined in this section.
- i. One or more sensitivity standards (blocks) compatible with the level of examination severity and operating procedures.
- j. A supply of methyl cellulose for preparation of scanning couplant and a small container of oil for coupling angle wedges to transducer elements.
- k. A 6-foot (2 meters) retractable pocket rule.
- l. A 6-inch (150 millimeters) metal rule with divisions of $\frac{1}{16}$ inch (1.5 millimeter) or less.
- m. A pocket notebook, pencils, soap stone, crayons, and other devices required for appropriate marking.
- n. Reflector locator plots, a pocket calculator, or similar device for determining reflector locations.
- o. A supply of forms for reporting results of examinations.

7.5.3 Periodic Equipment Checks

7.5.3.1 General

Since determination of the reflector location and size is the primary intent of an ultrasonic examination, it is essential for the instrumentation to yield an accuracy commensurate with the examination requirements. Before any new instrument or component is employed for weld examination, it should be examined to determine its performance characteristics with respect to industry and specification requirements. Normal wear and usage also produce performance changes which necessitate a periodic reexamination of previously determined characteristics.

To ensure that the equipment's internal and external controls function within the accuracies and tolerances of the equipment manufacturer, the operator's written procedures, and certain nationally or internationally published standards, the equipment should be calibrated to properly set and traceable measurements held at the National Institute of Standards and Technology (NIST) or other national standards agency. A standard operating procedure and quality control manual should detail the method adapted to assure traceability. The time intervals shown in Table 1 are recommended for calibration of NDE equipment.

Prior to and at regular intervals during an inspection job, routine performance checks and calibrations (also termed) should be carried out. The routine for these, including the equipment used, the frequency of each test, and the course of action if the instrument cannot be calibrated should be described in the inspection companies written procedure. The recommended time intervals for these equipment checks are shown in Table 2.

7.5.3.2 The IIW and IOW Standards

Figure 4 presents the IIW standard, a recognized test reference for evaluating sensitivity, sweep linearity, and shear wave transducer index point and angle. The IOW standard, see Figure 5, is less commonly known but affords a means of establishing shear wave beam characteristics and profiles. It may also be employed to check the accuracy of the beam index and angle obtained from measurements on the large hole of the IIW block and for assessment of the resolution characteristics of instrument-transducer combinations.

The IIW and IOW standards are available from normal commercial sources but are simple enough to be fabricated in any well-equipped machine shop; however, a number of rules should be observed when preparing calibration standards. First, the material should be similar in chemical composition and acoustical properties to the material to be examined. For offshore structural examinations, blocks fabricated from straight carbon or carbon-manganese steels are appropriate. The steel should be of the fully deoxidized type and subjected to a hardening heat treatment at 1650°F (900°C) for 1/2 hour followed by water quenching to room temperature plus subsequent tempering at 1200°F (650°C) for 3 hours for the purpose of minimizing "noise" and acoustical anisotropy. Prior to final machining, the blank stock should be machined on the surfaces to be utilized in the finished standard, followed by an ultrasonic examination to ensure that the blank is free of defects or flaws which will interfere with its subsequent use. Once accepted for final machining, stock removal should be restricted to the surfaces indicated on the drawings or those requiring acoustical coupling in use. Unnecessary machining, plating, and surface treatments result in wall echoes and diminish the usefulness as a reference standard.

Table 1—Recommended Maximum Time Intervals Between Recalibration and Recertification of NDE Equipment

NDE Equipment	Time Interval
Ultrasonic compression wave gauge	12 months
Certification on UT compression wave step blocks	At purchase/manufacture have certificate on file with serial number
Ultrasonic shear wave flaw detector	12 months
Certification on shear wave test blocks	At purchase/manufacture have certificate on file with serial number
Hall-effect gauss (tesla) meter	1 year
Reference magnet for HE gauss (tesla) meter	1 year
AC Yoke (10-pounds lift test)	1 year
Mechanical gauge used for grind depth	1 year
Light meter	Annually

7.5.3.3 Check of Horizontal Linearity

To check the horizontal or (sweep) linearity of the instrumentation, it is necessary to adjust multiple echoes obtained from a longitudinal wave transducer placed on the flat surface of the IIW block to match equal divisions on the overlay grid or horizontal scale of the CRT. The leading edge or left hand side of each echo signal should coincide with the divisions of the horizontal scale (see Figure 6). The preferred number of echoes is four or five, depending on the possibility of dividing the selected range into units that coincide with major divisions of the horizontal scale.

In most instances, it is recommended that the highest frequency be utilized as this produces the sharpest indications and improves the accuracy of measurement. It should also be realized that the distance between the initial pulse indication and the first echo signal is always greater than the distance between successive multiple echoes; therefore, the alignment should commence with the first echo signal and not with the initial pulse.

After aligning the echoes with the scale, one should determine the deviation of positions of each echo from the scale mark. The maximum noted deviation should not exceed 1 percent of the full scale range. Checks on selected ranges of 5 inches (125 millimeters) and 10 inches (254 millimeters) are recommended.

Table 2—Recommended Standards and Maximum Performance Check Intervals for NDE and Mechanical Measuring Equipment

Equipment Performance Checks (Standardization)	Standard	Time Interval
Compression wave UT unit		
Readout over thickness range under examination	Compression wave standard	Prior to examination
<i>Shear wave UT unit:</i>		
Horizontal (sweep) linearity	IIW Block	40 hours
Angle beam transducer index (sound entry) point	IIW Block	40 hours
Transducer beam angle	IIW Block	
Beam profile	IIW Block	Prior to examination
Resolution	IOW Block	Prior to examination
Sound path distance	IIW, DSC, or AWS	Prior to examination
Reference sensitivity	per acceptance criteria	Prior to examination
<i>Hall-effect gauss (tesla) meter:</i>		
Zero scale reading	Zero gauss chamber	Prior to examination
Reference magnet reading	Reference magnet	Prior to examination
Mechanical depth measurement device		
Zero scale reading	None	Prior to examination
Reading at 0.100 inch	Depth ref standard	40 hours

7.5.3.4 Determination of Angle Beam Transducer Index Point

The transducer is positioned on the IIW block as indicated in Figure 7 and moved parallel to the sides of the calibration block until the maximum echo is obtained from the curved quadrant. The transducer index point (sound entry) is then directly above the center of the quadrant. This point should be marked with a scribe on the side of the transducer housing or on the side of the plastic wedge.

7.5.3.5 Determination of Transducer Beam Angle

Using the IIW block, one should obtain a maximized echo signal from the 2-inch (50 millimeter) or $1/16$ inch (1.5 mm) diameter hole. The larger hole is employed for measuring the angle of transducers smaller than 70 degrees and the small hole for measurements of 70 degrees or more. When the echo is at a maximum, the angle is indicated by the engraved numbers on the side of the block at the point directly below the index mark of the transducer, previously determined (see Figure 8).

Beam angle determination using the large hole in the IIW block may contain a significant error; therefore, it is recommended that transducers employed for evaluating discontinuity position and size be further calibrated using the IOW block. Again, one should maximize the echo on one of the small holes in the IOW block and very carefully measure the metal path distance from the index point of the transducer to the front surface of the hole. Then we should divide this measurement by the distance of the hole from the surface on which the transducer was placed to obtain the secant of the transducer angle. The resultant value is sufficiently accurate for ultrasonic weld examination of offshore structures.

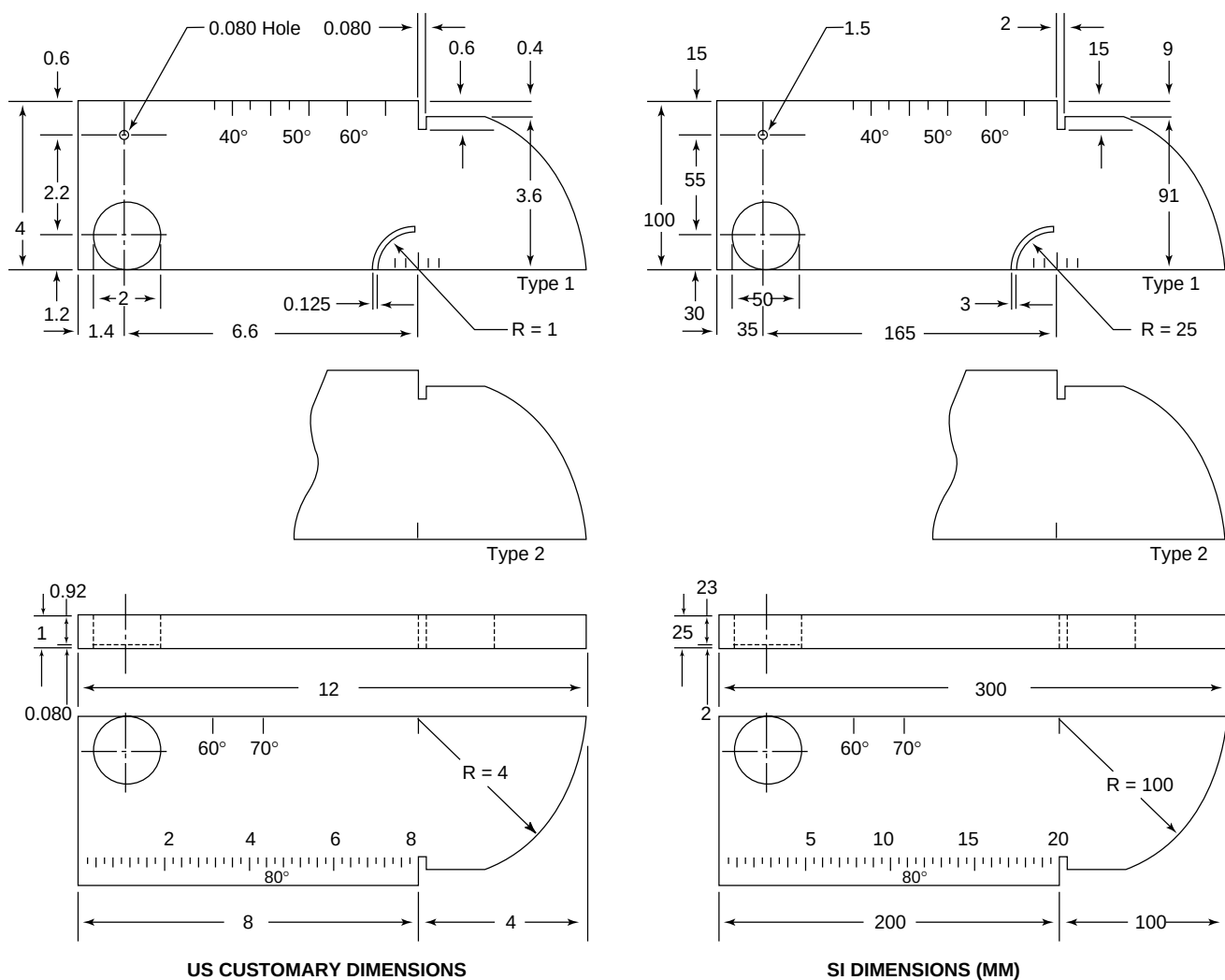
7.5.3.6 Investigation of the Beam Axis

The IOW block should be employed to determine the characteristics and shape of each beam profile. First, the transducer should be examined to ascertain that the beam has only one major axis. Sometimes transducers exhibit two or more beams of equal or near-equal intensity. Obviously, these transducers are of little value in locating or measuring weld discontinuities. A check of this abnormality is achieved by maximizing an echo from one of the holes near the opposite surface of the block from the one in contact with the transducer. Slow back and forth movement of the transducer parallel to the edge of the block until the echo disappears should produce a reasonably smooth decay of the echo signal on both sides of the beam axis. An abrupt rise in echo as the amplitude is decaying denotes a beam profile abnormality. The intensity of any echo signal rise from a secondary axis should not exceed 10 percent of the major axis intensity.

7.5.3.7 Determining the Beam Spread

The *beam boundary* is defined as the surface of a cone where the echo intensity from a small reflector intersecting the beam will be some predetermined percent of the maximum echo obtained from the same reflector on the beam axis (see Figure 9). Commonly defined boundaries are those where the intensity is 6 decibels and 20 decibels below the maximum signal. In most cases, the beam appears as a cone emanating from the index of the transducer, but beam profiles of high frequency and large transducers are often found to exhibit a cylindrical section near the transducer resulting from the near field influence.

The IOW block is designed to facilitate the measurement of the cone angle at varying distances from the index point



Notes:

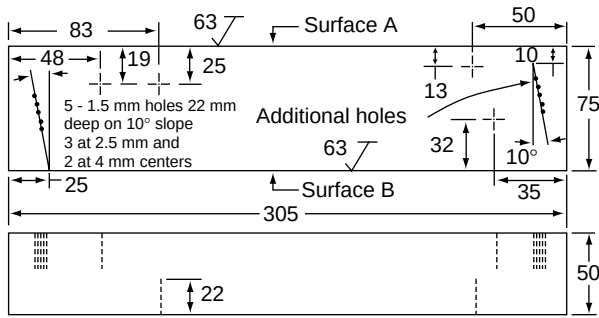
1. The dimensional tolerance between all surfaces involved in retaining or calibrating shall be within ± 0.005 inch (.13 millimeter) of detailed dimension.
2. The surface finish of all surfaces to which sound is applied or reflected from shall have a maximum of 125 $\mu\text{in. r.m.s.}$
3. All material shall be ASTM A36 or acoustically equivalent.
4. All holes shall have a smooth internal finish and shall be drilled 90 degrees to the material surface.
5. Degree lines and identification markings shall be indented into the material surface so that permanent orientation can be maintained.
6. Other approved reference blocks with slightly different dimensions or distance calibration slot are permissible.

Figure 4—International Institutes of Welding (ITW) Ultrasonic Reference Blocks

for plotting the profile in both the vertical and horizontal plane. To construct the vertical profile, the holes are scanned in succession from faces A and B of the block. At each hole the point corresponding to the probe index is marked on the side of the block when the echo is at maximum height. The transducer is then moved backward and forward parallel to the edge of the block, marking the point where the echo height has dropped to the pre-selected intensity, such as 20 decibels. In lieu of observing the decay of a cathode ray tube echo signal to the percentage represented by the decibel value, it is suggested that the decibel attenuator be employed to determine the precise

measurement of the drop. For example, assume someone desires to construct a 20 decibel beam boundary. After the echo signal from a hole has peaked, that person can set the sensitivity to produce a $3/4$ vertical scale echo signal and increase the sensitivity by 20 decibels. Moving the transducers backward and forward to bring the echo signal back to $3/4$ scale height will define the point where the beam is one-tenth (–20 decibels) of the maximum without introducing measurement errors due to vertical nonlinearity.

When the transducer index is in the forward position, the hole is located on the bottom of the beam, and when in the reverse position, it is on the top of the beam. The distance



Dimensions in millimeters, tolerance ± 0.1 mm.
Grind surfaces A and B to indicated surface roughness in microinches.

Figure 5—Institute of Welding (IOW) Block

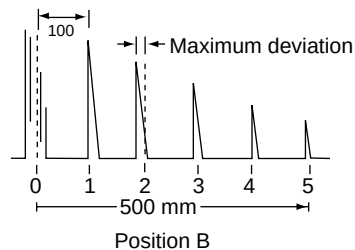
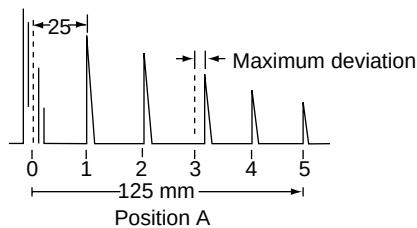
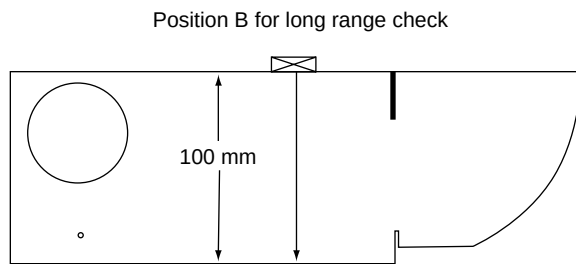
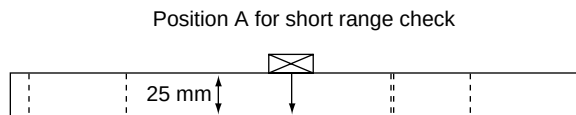
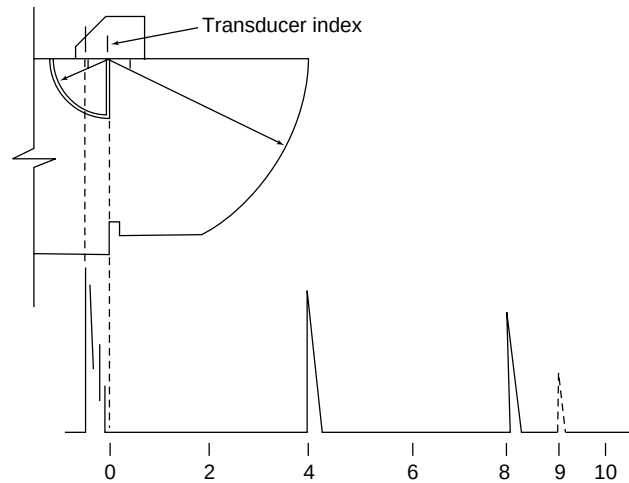


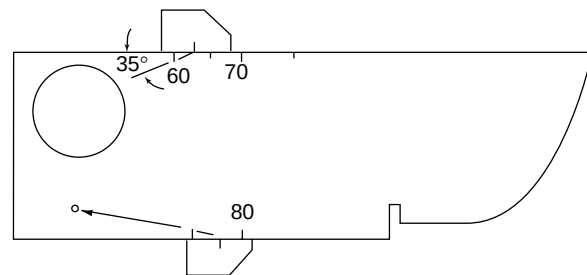
Figure 6—Check of Sweep Linearity

measured from the index to the beam edge on each hole represents the width of the beam, measured parallel to the contact surface, at the depth of the hole below the surface (see Figure 10). On completion of measurements on all holes within the sound path length of interest, the points are con-



Note: When the signal has been peaked to a maximum, the echo from the 100 mm radius of the IOW block should be adjusted to position 4 on a 0 to 10 scale. The second echo from a block with vertical slots should then be adjusted to appear at 8 on the scale. For blocks with an alternate 25 mm radius, the second echo should appear at 9 on the scale. With the amplitude at a maximum and proper scale adjustment, the index of the transducer is directly aligned with the center of the radius on the block. This point should be scribed on the side of the transducer.

Figure 7—IOW Block—Determination of Angle Beam Transducer Index

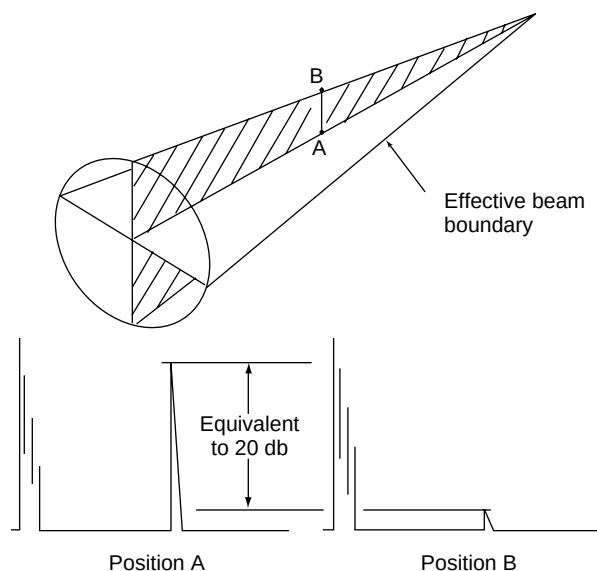


Note: The figures engraved on both sides of the IOW block permit direct determination of incident beam angles between 35 and 80 degrees. The angle is indicated under the index point when the echo is maximized on the small (1.5-mm) or large (50-mm) hole.

Figure 8—IOW Block Showing Determination of Transducer Beam Angles

nected to reveal the total sound beam envelope in the vertical plane. Points which obviously do not fall near a straight line should be remeasured to determine any error in the original analysis. Failure to reveal an error indicates that an anomaly exists in the beam which must be recognized during any discontinuity size measurement.

In addition to defining the actual beam boundaries for further use in precision discontinuity size measurement, these construction exercises reveal the distances the transducer must be moved at each sound path length to completely traverse a discontinuity $\frac{1}{16}$ inch (1.5 millimeter) in width



Note: Beam spread diagram indicating vertical and horizontal profile planes constructed from measurements obtained from IOW block. CRT patterns shows drop for 20 db beam profile.

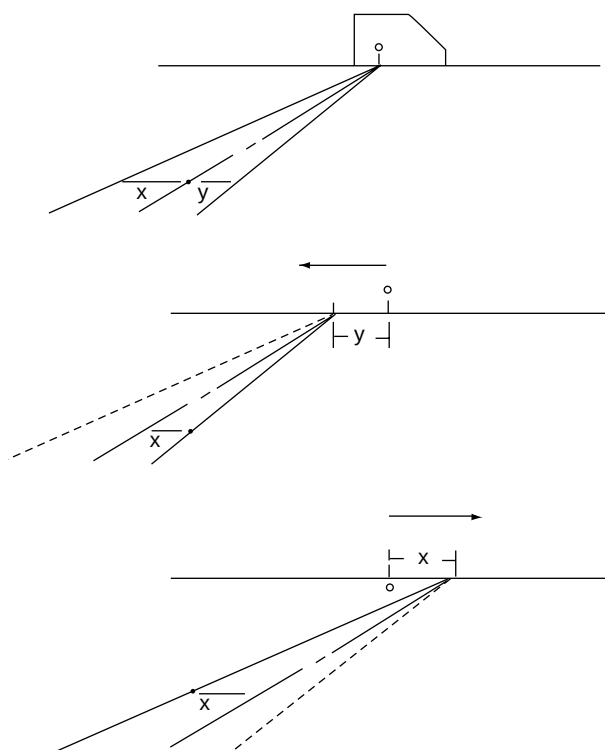
Figure 9—Determination of Beam Spread

By recording these movements, UT personnel may be able to quickly screen small discontinuities acceptable under the examination criteria without resorting to the tedious task of measuring each individually.

To determine the beam spread in the horizontal plane, one places the transducer on surface A or B of the IOW block to obtain a maximized echo from one of the calibration holes, avoiding any angular rotation of the transducer. Using a rule or straight edge as a guide, one moves the transducer away from the edge of the block until the intensity of the echo has diminished by 20 decibels (see Figure 11). The half-beam spread at this distance is found by subtracting the drilled depth of the hole from the distance moved away from the edge. The beam spread derived by scanning along the calibration hole will be slightly less than when derived by scanning across it. At the 20 decibels edge, however, the difference is very small. The procedure is repeated on the opposite side of the transducer and for all points within the beam path distance of interest. A beam spread plot in the horizontal plane can then be constructed in the same manner as in the vertical plane.

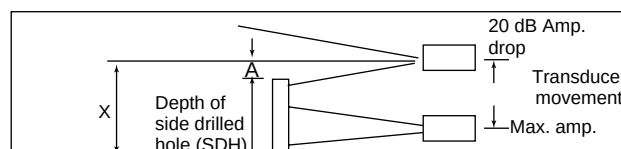
7.5.3.8 Evaluating Resolution of the System

The IOW block is employed to assess the resolution capabilities of each instrument-transducer combination. The ability to independently resolve two closely spaced reflectors on the sound path is a mandatory requirement for accurate weld-quality assessment. For example, the differentiation of a root discontinuity from the root protrusion of an acceptable weld is required when examination must be conducted from one side only.



Note: Movements indicated for construction of top and bottom points at one distance along the beam path.

Figure 10—Measurement of Beam Profile in the Vertical Plane



$A = X - \text{Depth of SDH}$

Figure 11—Measurement of Beam Spread in the Horizontal Plane

Using the five 1.5-millimeter resolution holes as reflectors, one should be able to clearly separate the individual holes on 4-millimeter spacings with a 45-degree transducer oscillating at 2.25 megahertz. The resolution of more closely spaced holes at this frequency and with larger angle transducers is difficult, requiring the use of higher frequencies. For critical weld assessments, the use of transducers oscillating at frequencies of 4 megahertz and higher may be required.

7.5.4 Sound Path Distance Calibration

Accurate location of discontinuities requires an accurate calibration of the horizontal scale on the cathode ray tube. This is accomplished by use of reference standards which

produce reflections from angle beam probes at known distances. The IIW block DSC and the DC block described in the American Welding Society's *Structural Welding Code* are adequate for this purpose.

Note: These blocks do not produce exact equivalents between the SI and customary systems and due consideration to this fact should be given for critical examination.

7.6 PREPARATION FOR EXAMINATION

Prior to attempting evaluation of a weld in the structure, UT personnel should become thoroughly familiar with the design by reference to the specifications and construction drawings. The nominal thickness of specific connections should be noted and compared to values obtained by measurement during the weld examination.

The results of the visual inspection during the fit-up should be reviewed to ascertain areas likely to result in poor weld quality or areas where the root location has been modified.

A final visual inspection of the weld should be performed for detection of undercut, incomplete fill or excess roughness which would interfere with a meaningful ultrasonic examination.

7.6.1 Index of Weld Root

Subsequent to the weld bevel preparation, including any field trimming during fit-up, and prior to welding of the root pass, the member from which scanning is to be performed should be scribed or punch-marked at a specific surface distance from the root face to ensure an exact index of the root face location after completion of welding. See Figure 12. This marking is particularly important for T, K, and Y connections where measurement from other index points becomes difficult or impossible after completion of welding. The distance of the scribe line or line of punch marks from the root face is optional, but care should be exercised to displace the marks a sufficient distance from the bevel edge to assure retention after welding. These marks provide an exact location of the root face during the ultrasonic examination and aid in differentiation of root defects from acceptable root protrusions.

Pile splice bevel preparation should be index marked on the stabbing guide side of the preparation at the yard before load-out. The opposite side root preparation can be marked after pile cutoff and beveling at the installation site. Four marks around the circumference yield adequate marking if a banding strap is employed as a transducer alignment guide during scanning of the root area (see Figure 13).

7.6.2 Surface Preparation

The surface from which scanning is to be achieved should be cleaned to remove all scale or coating (for example by grit-blasting or power brushing) to assure continuous coupling during the examination, particularly if flaw sizing is

based on amplitude technique. Uniform thin film coatings must be accommodated by use of transfer corrections. Where local conditions of roughness or weld-splatter exist, it is recommended that the local areas be smoothed by methods other than grinding (a sander on a soft pad is one acceptable method).

Regardless of the quality of the surface finish, it is recommended that transfer corrections be utilized in all cases.

7.6.3 Thickness Measurement

The thickness of each member from which scanning is to be achieved should be determined and recorded for use in the flaw location determinations. Thickness should be ascertained at four points around the circumference on tubular members and every six feet along welds in flat plate connections to assure detection of allowable variations.

The value of thickness obtained should be compared to the construction drawing requirements and any discrepancies outside of specified tolerances reported to the inspector.

7.6.4 Base Metal Examination

The entire area from which scanning is to be achieved should be examined by the longitudinal wave technique to assure freedom from lamination or other laminar-type flaws which could interfere with sound wave propagation.

If defects or considerable variation in attenuation are found, it is important that their influence on the weld examination be taken into account and the scanning technique adjusted to ensure complete examination of the weld.

7.7 SCANNING TECHNIQUES

Probe manipulations employed to detect discontinuities in the weld area are termed *scanning* and the success of the entire examination depends on the selected probe, instrument sensitivity, and transducer movements employed during this phase of the examination.

7.7.1 Probe Selection

The selection of a scanning probe is generally a compromise between sensitivity, coverage, resolution, and mechanical coupling stability. Large high-frequency probes produce a narrow ultrasonic beam of high-resolution capabilities and a reduced sensitivity to detection of discontinuities obliquely oriented to the sound beam. Flat probe contact (and a constant incident angle) on cylindrical or curved surfaces is a difficult task with large probes, resulting in a preference for small probe dimensions when examining welds in small diameter pipe. Reducing the size of the probe for a fixed frequency will expand the beam profile included angle and aid in the detection of discontinuities moderately mis-oriented from perpendicularity with the beam axis. Use of miniature-size probes results in a broad beam divergence

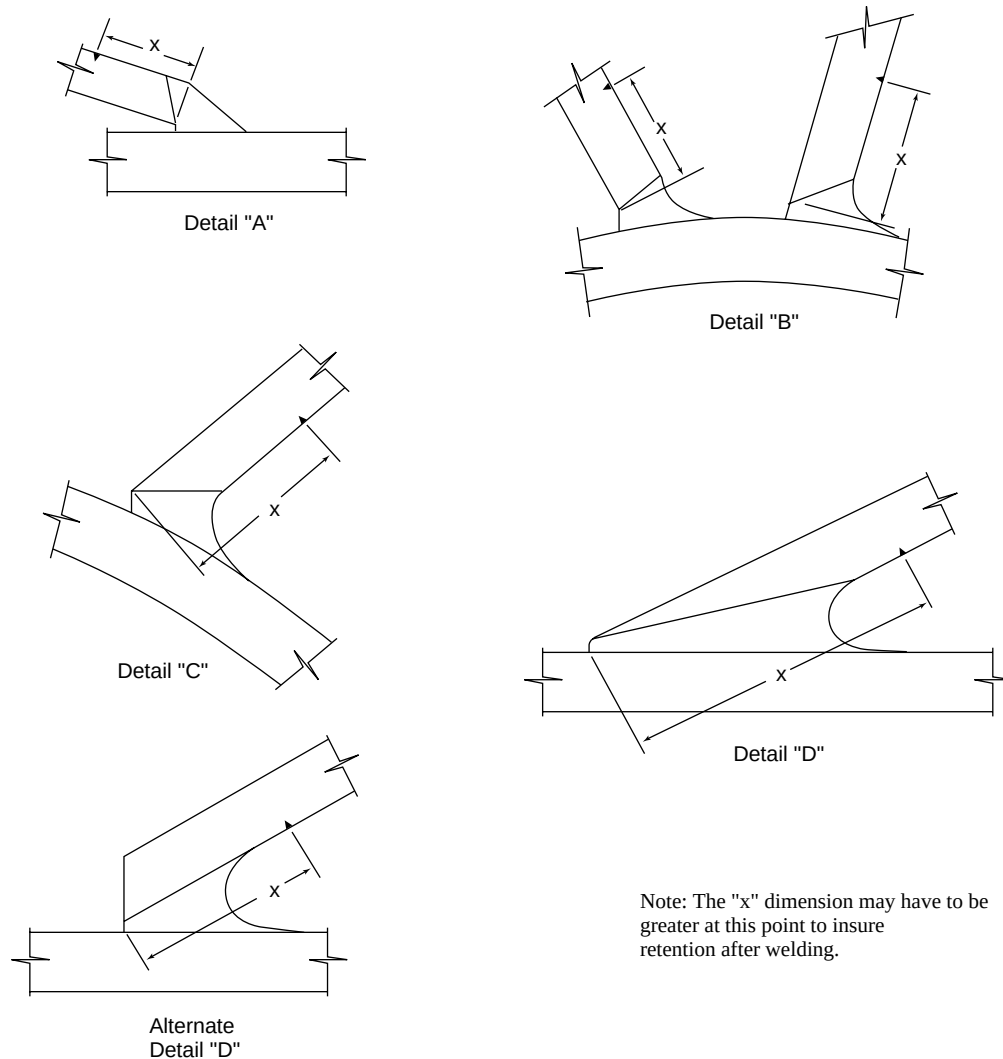
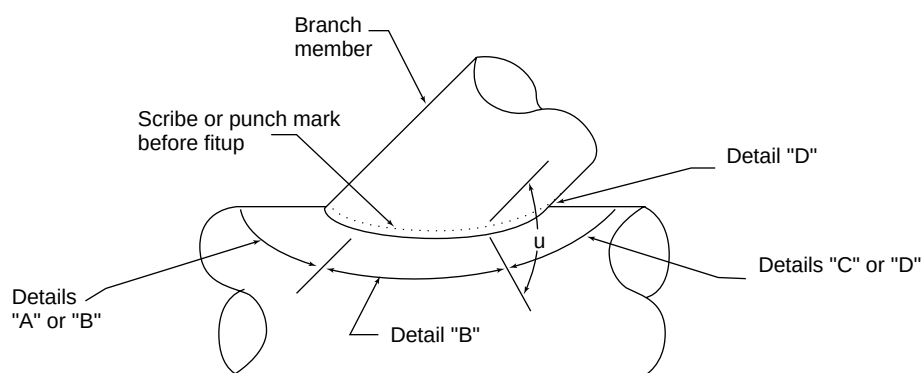


Figure 12—Weld Root Index

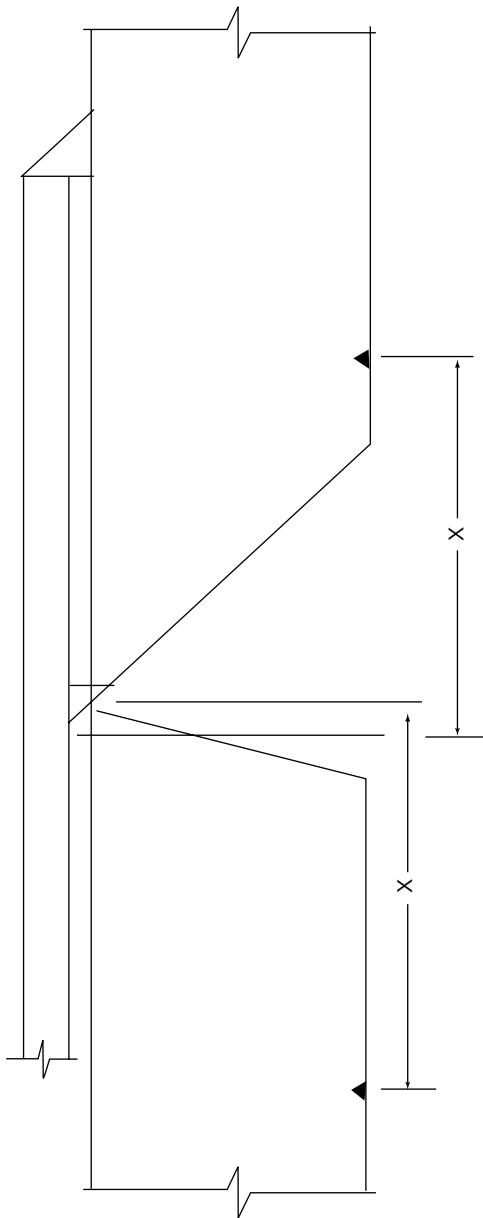


Figure 13—Weld Root Marking of Members for Installation Pile Splice Welds

and a consequent loss of power with a resultant steep decay of the distance amplitude curve. Consequently, examination of welds in thick sections with miniature and small dimension probes generally will require two or more scans at different sensitivity levels and base line adjustments to ensure that all discontinuities of interest will reflect sufficient energy to be visible on the cathode ray tube.

For angle beam scanning of weld discontinuities of the size of interest in offshore structural fabrication, a probe with a transducer element approximately $\frac{1}{2}$ inch (12.7 millimeters)

round or square, operating between 2 megahertz and 2.25 megahertz is suggested as a good compromise of all desirable attributes. The beam produced from this probe will permit examination of thick sections with moderate beam decay, resolve most discontinuities of interest without indicating the presence of fine inclusions within the steel, and exhibit a beam profile included angle sufficiently broad to ensure that discontinuities at all orientations between the nominal 45-degrees, 60-degrees, and 70-degrees angles will yield a significant echo signal. Other transducer frequencies and sizes may be desirable for specific applications.

7.7.2 Sensitivity

Scanning must ensure the detection of all discontinuities of interest; therefore, a sensitivity greater than that required to produce a full-scale echo signal from the reference reflector is always employed. An increase in sensitivity 6 decibels above that required to produce a full-DAC echo signal from the reference reflector will ensure full-DAC echo signals for discontinuities oriented seven to ten degrees from perpendicular when scanning with the recommended probe. An additional increase of 6 decibels (12 decibels total) above the reference will aid in detection of transient reflectors at high scanning speeds. Higher scanning sensitivities are desired by some UT personnel, but caution should be exercised to avoid large echo signals from insignificant or irrelevant discontinuities which result in time-consuming evaluations and promotes eye fatigue.

7.7.3 Extent of Coverage

7.7.3.1 The complex geometry of welded connections on offshore structure particularly T, K, and Y connections, typically requires the use of nominal angle transducers (i.e., 45-degree, 60-degree, and 70-degree) in multiple scans of the entire circumference and almost always from the brace side of the weld only. The inspection of thin wall sections may not improve with the use of steer angle transducers. Thick wall diagonal braces with full-throated weld connections may also require the use of an 80-degree transducer to ensure that the sound beam intercepts the root area. In all scans the transducer cant angle is continually adjusted to maintain the beam perpendicular to the length of the weld. See Figure 14 for definitions of nomenclature associated with tubular member intersections. The recommended effective probe angle for examination of the root area should be that which produces an incident angle nearest to perpendicular to the anticipated weld discontinuity. UT personnel are cautioned to be alert for changes in intercept angles and avoid 30-degree incidence on potential discontinuities which cause mode conversion and a loss of echo signal amplitude. (See Section 7.8 for the effects of surface geometry on the incident angle.)