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

API RECOMMENDED PRACTICE 2X
THIRD EDITION, SEPTEMBER 1996

EFFECTIVE DATE: NOVEMBER 1, 1996

American
Petroleum
Institute

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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*

ANSI[1]/AWS[2]

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*

ASNT[3]

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

ASTM[4]

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

[1]America National Standards Institute, 1430 Broadway, New York, New York 10018.

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

[3]American Society of Nondestructive Testing, 4153 Arlingate Plaza, Columbus, Ohio 43228-0518.

[4]American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428.

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 then 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:

a. Qualification of all welders and welding procedures to be employed in fabrication, especially for tubular member connections.

b. 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 evaluate 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

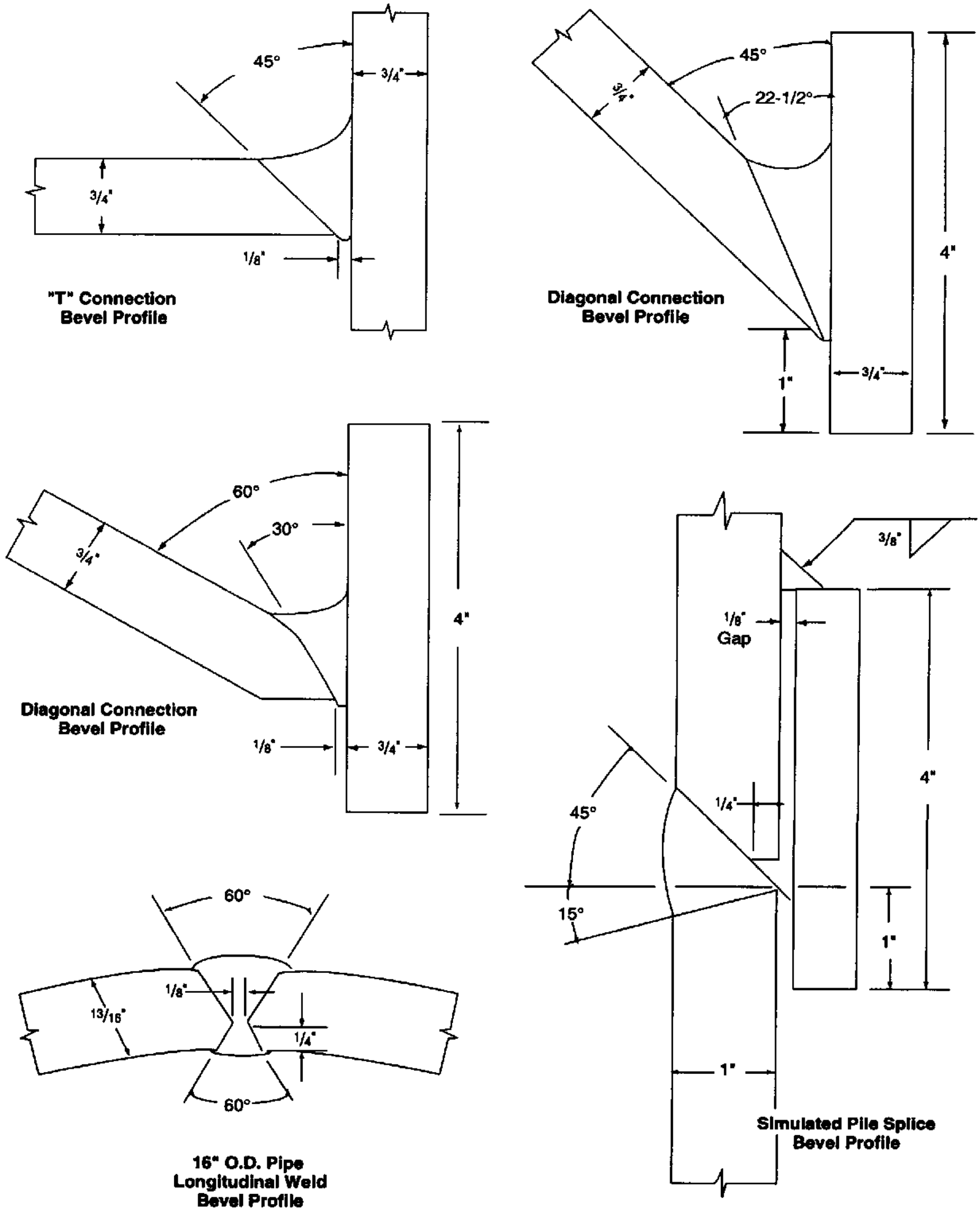
The practical test determines the candidate's ability to detect and evaluate weld discontinuities of interest. Demonstration of such ability is the object of the qualification examination and should be considered of greater significance than all other requirements.

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.

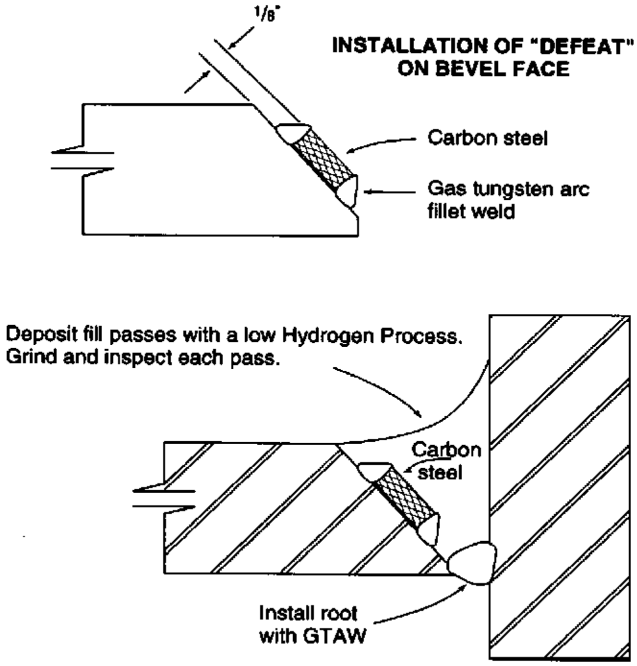
Test coupons may contain natural discontinuities or artificial reflectors consisting of non-metallic inserts in the weld deposit, slots or holes machined in the weld, or thin steel inserts fillet welded to bevel preparations to simulate incomplete fusion. See Figure 2 for details. Mock-up structures 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:

a. MT—Length, location on cap surface, and location along weld (from Y).
b. 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:

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

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

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.

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 ¼ 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 ± 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 ½ 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 filet welds yields questionable results, particularly in sections of thin to medium thickness. Applications where the filet 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

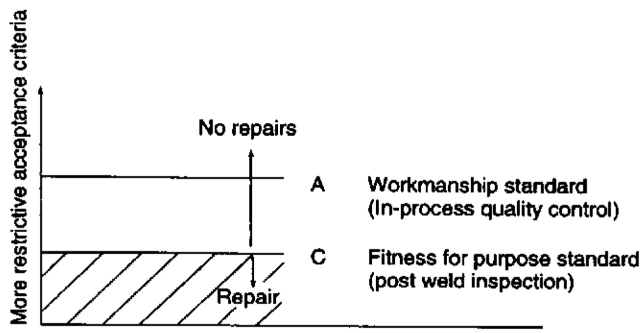


Figure 3—Significance of Discontinuities

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. 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 ¾ 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, ½ inch to 1 in. (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 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 ½ 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 anisotrophy. 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)	4 months
DC Yoke (40-pounds lift test)	4 months
Mechanical gauge used for grind depth	4 months
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
Shear wave UT unit:		
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
Hall-effect gauss (tesla) meter:		
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.

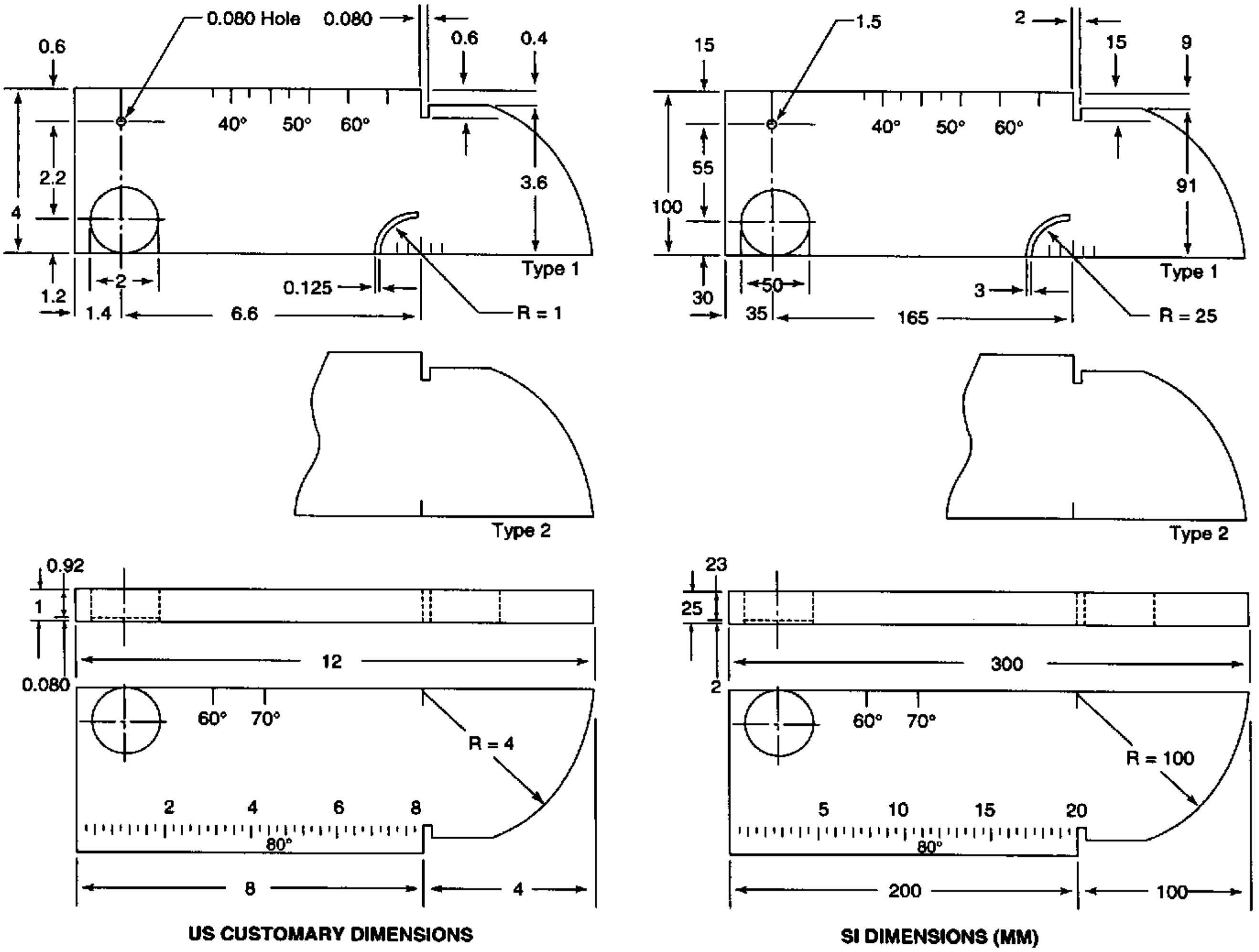
7.5.3.6 Investigation of the Beam Axis

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

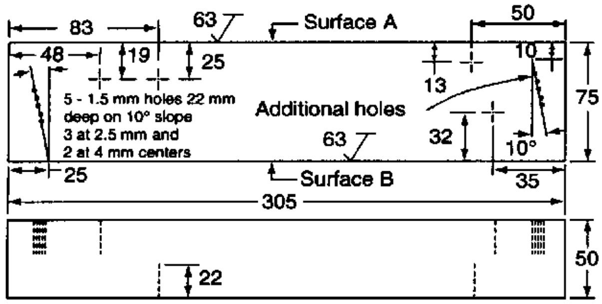


Notes:
1. The dimensional tolerance between all surfaces involved in retaining or calibrating shall be within ±.005 inch (.13 millimeter) of detailed dimension.
2. The surface finish of all surfaces to which sound is applied or reflected from shall have a maximum of 125 μin. r.m.s.
3. All material shall 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 permissable.

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 ¾ vertical scale echo signal and increase the sensitivity by 20 decibels. Moving the transducers backward and forward to bring the echo signal back to ¾ 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

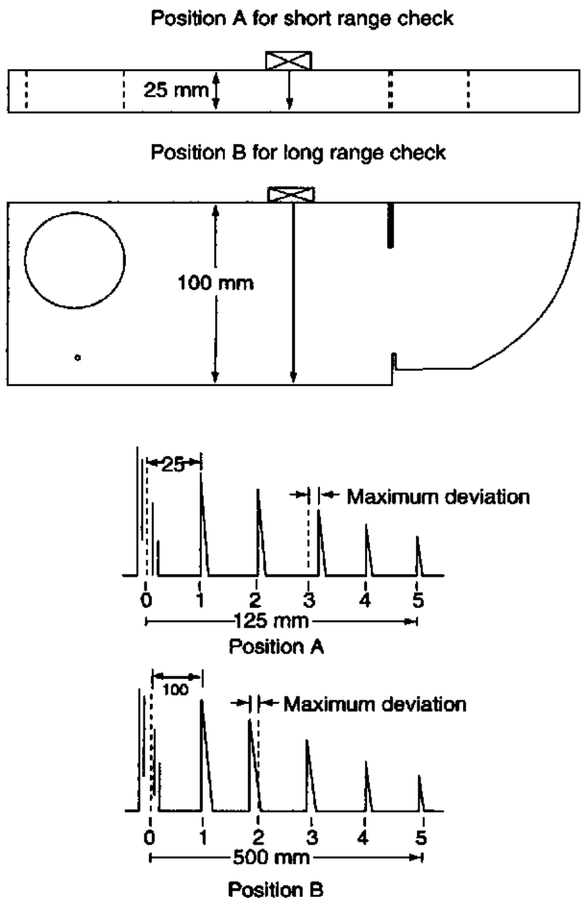
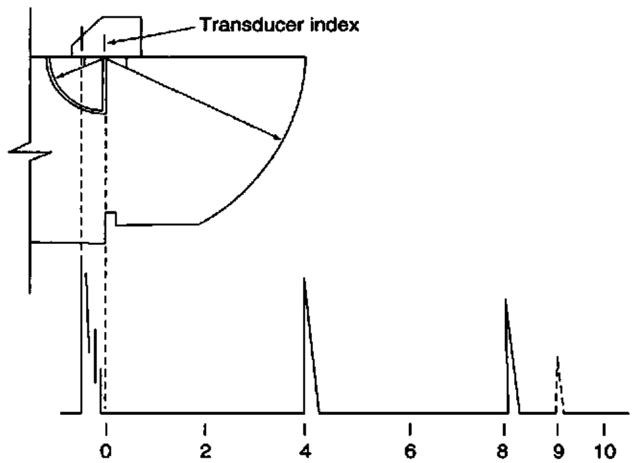
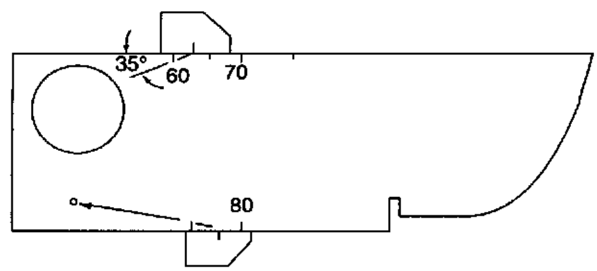


Figure 6—Check of Sweep Linearity



Note: When the signal has been peaked to a maximum, the echo from the 100 mm radius of the IIW 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—IIW Block—Determination of Angle Beam Transducer Index

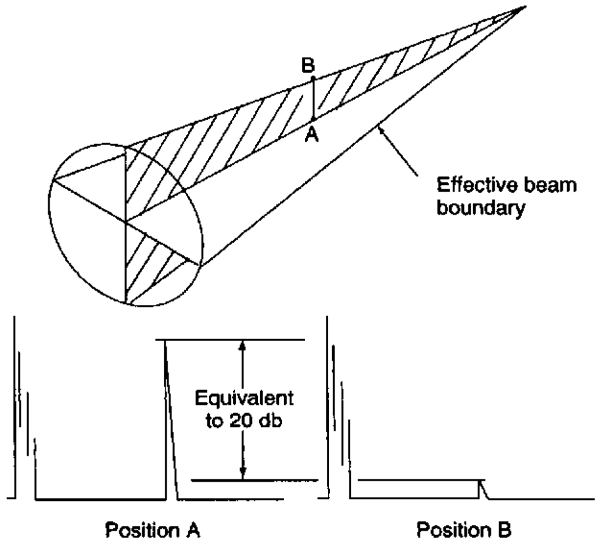


Note: The figures engraved on both sides of the IIW block permit direct determination of incident beam angles between 35 and 80 degrees. The angle is indicated under the index point when the echo is maximized on the small (1.5-mm) or large (50-mm) hole.

Figure 8—IIW Block Showing Determination of Transducer Beam Angles

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 connected 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 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.

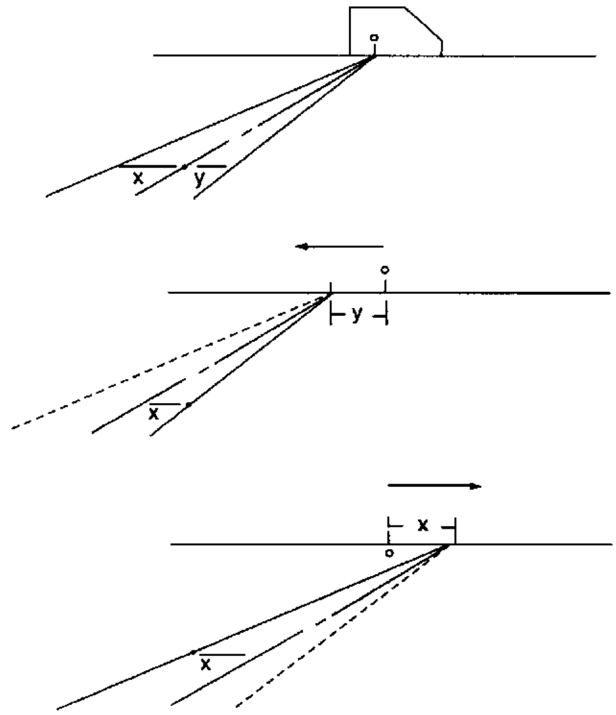
Figure 9—Determination of Beam Spread

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.

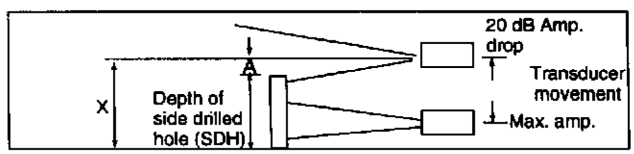
7.5.3.8 Evaluating Resolution of the System

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 - 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 misoriented from perpendicularity with the beam axis. Use of miniature-size probes results in a broad beam divergence

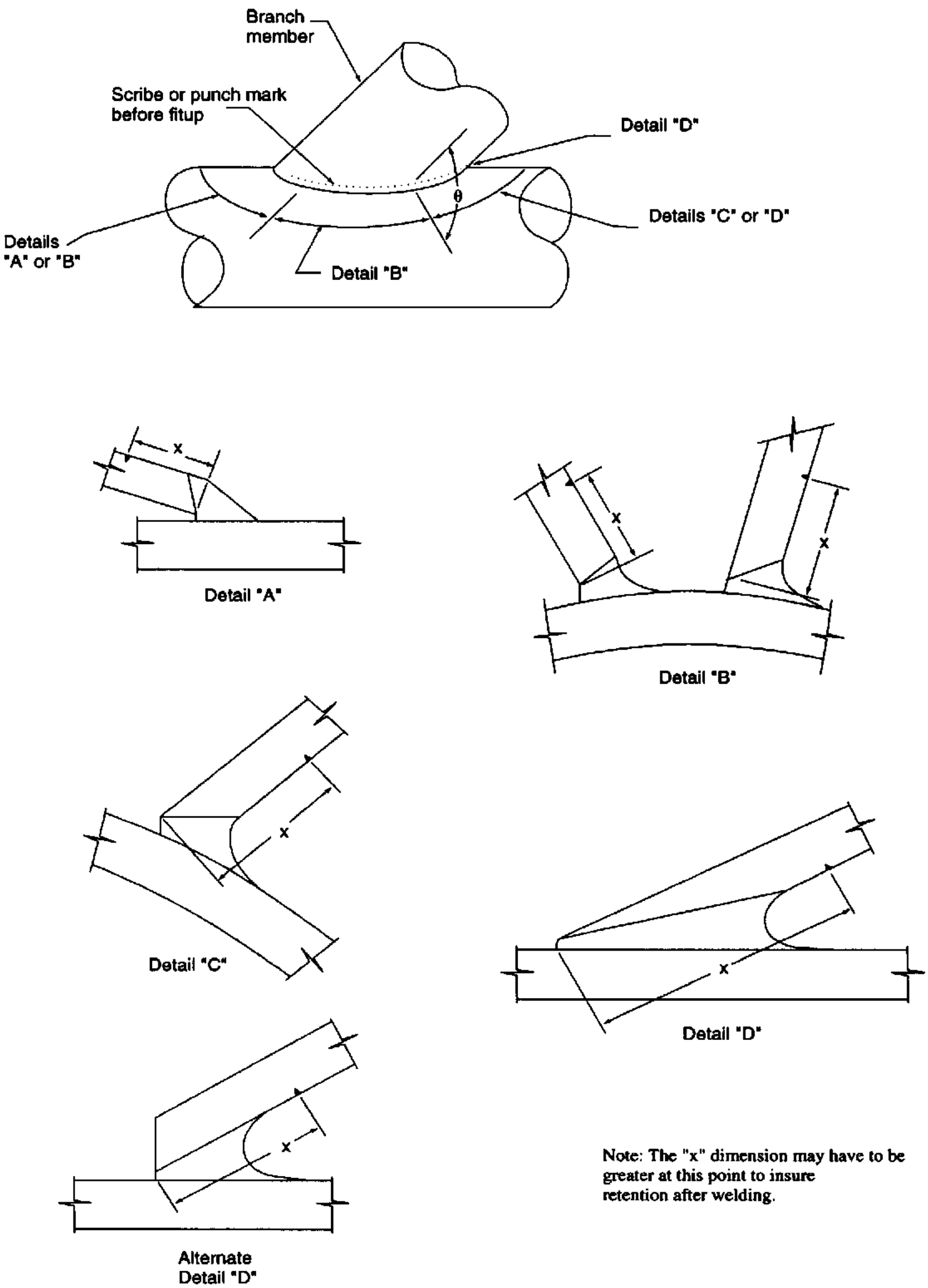


Figure 12—Weld Root Index

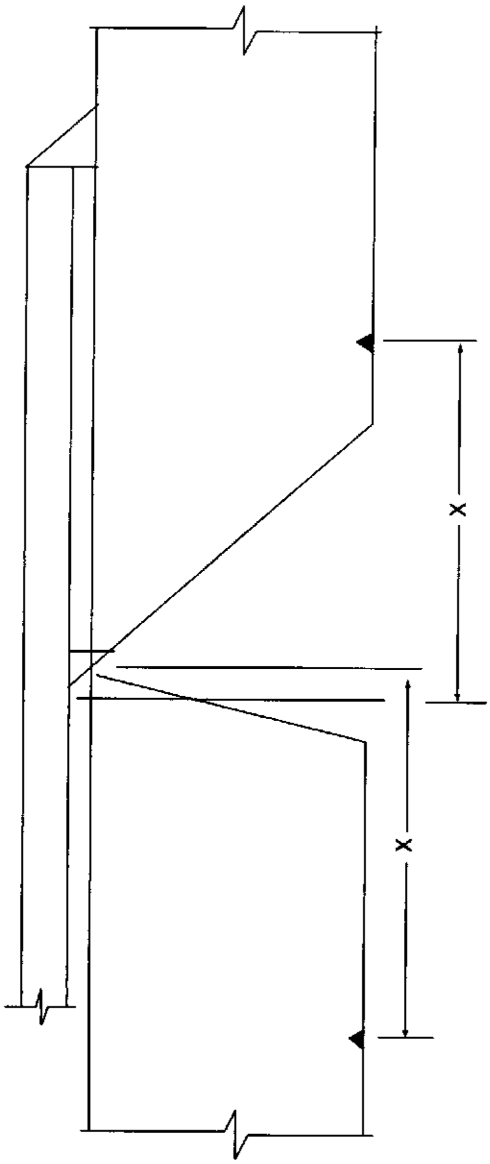


Figure 13—Weld Root Marking of Members for Installation Pile Splice Welds

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 ½ 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).

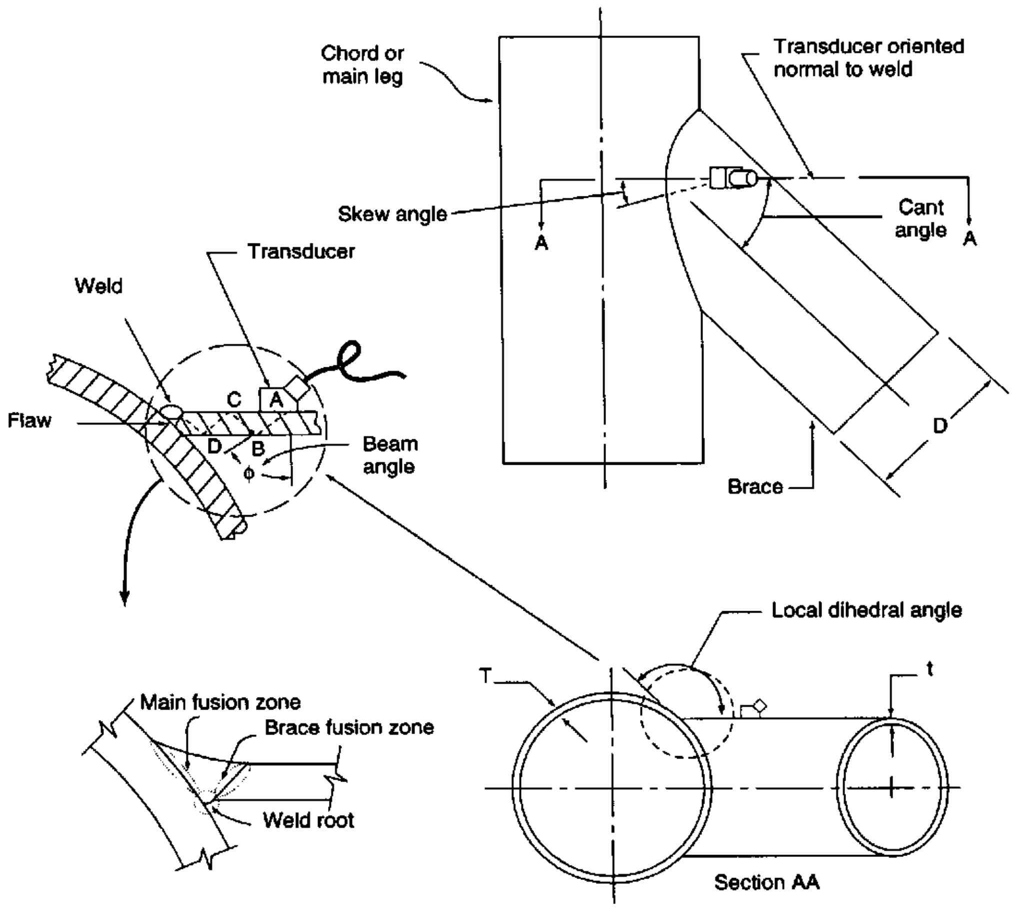


Figure 14—Parameters Associated With Geometry of Pipe Intersection

7.7.3.2 Examination of weld root areas separately from the remainder of the weld is recommended. If the probe is moved parallel to the toe of the weld at the intercept distance to the root protrusion, any change in the root geometry can be ascertained by a lateral movement on the horizontal scale of the CRT. The generally continuous echo from the root protrusion indicates a sound weld-whereas, an interruption or shift in echo signal position indicates a change in root geometry and the presence of a discontinuity. Detection of the metal path distance shift is enhanced by expanding the horizontal scale to include only the region of interest (see Figure 15).

7.7.3.3 After examination of the root area, the remainder of the weld is scanned using a back-and-forth motion accompanied by a slight rotational movement (see Figure 16). The length of the transverse movement must be sufficient to ensure that the center of the beam crosses the weld profile in two directions, a full-vee path, or a surface distance equivalent to approximately one and one-forth times the skip distance (see Figure 17). When the weld reinforcement extends significantly beyond the edge of the original bevel, the length of transverse movement may require evaluation in the one and one-half and second skip distances of the sound beam. Each lateral movement of the transducer should overlap the last by not less than 10 percent of the probe width to assure full examination of the weld.

7.7.3.4 Additionally, axial weld scanning is recommended for welded connections in 50-ksi material and greater with thicknesses 1 inch (25 millimeters) and larger for the detection of transverse planar discontinuities (see Figure 16). Scanning coverage should be parallel to the weld axis in two directions and include transverse scanning atop the weld reinforcement surface, where practical. If scanning atop the reinforcement is not practical, all efforts for axial weld scanning should be performed from the adjacent base material, each side of the weld. A 45-degree probe angle is recommended as the primary scan for the detection of transverse planar discontinuities. Examination results should be reported to the owner/operator for disposition.

7.7.3.5 All butt weld joints should be examined from each side of the weld axis and both faces where accessible.

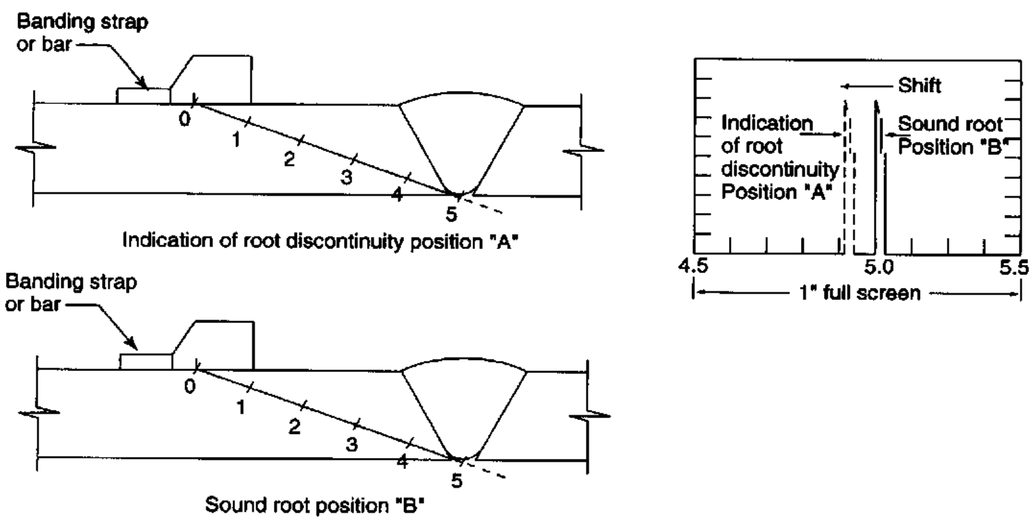


Figure 15—Weld Root Examination

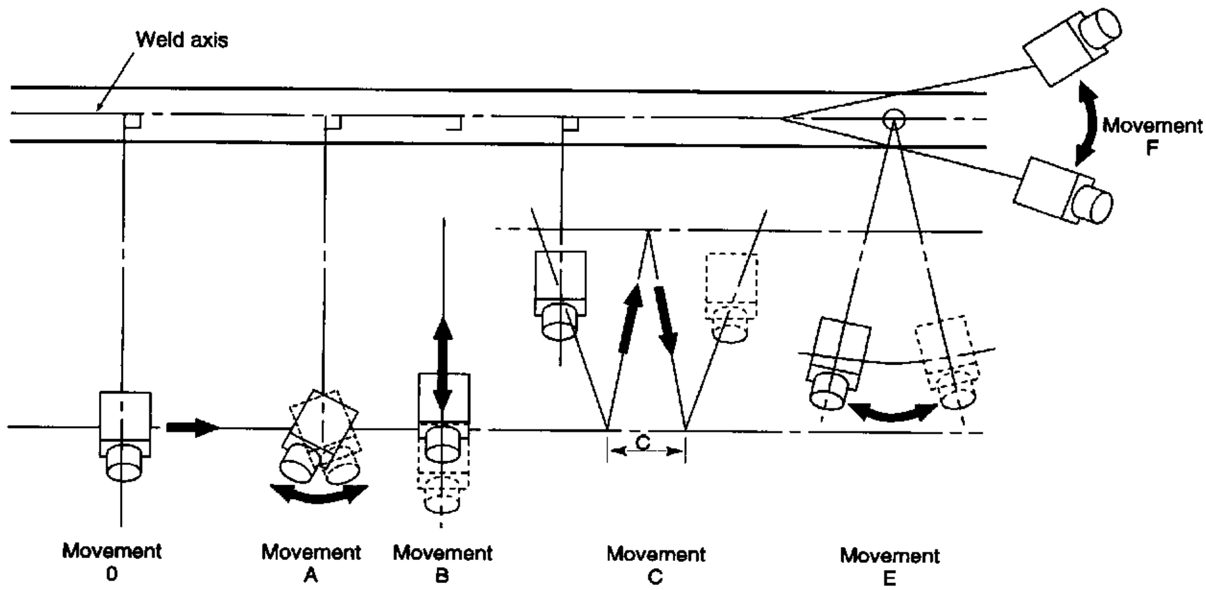


Figure 16—Scanning Patterns

Corner, T-joint, and diagonal-joint welds should be examined from one side of the weld axis only and both faces where accessible. It is intended that as a minimum, these welds be examined through the entire volume of the weld and heat-affected zone.

7.7.4 Transfer Correction

Transfer correction values can be determined as follows:

a. A correction of instrument sensitivity is required to compensate for differences between the reference standard surface roughness, contact area, and acoustical attenuation characteristics and those of the part being examined. Amplitude transfer corrections should be performed at initial examination of a group of similar welds and/or materials and whenever significant changes in surface roughness, condition profile, or coating is observed. Weldment surface conditioning should be performed if the transfer correction exceeds + 6 decibels.

b. Measurement is achieved by employing two angle beam probes of the same type, one acting as a transmitter and the second as a receiver (see Figure 18). The probes are directed at each other on the reference standard at one skip distance and the signal adjusted to 75 percent of screen height. The probes are repositioned to achieve a peaked signal at two

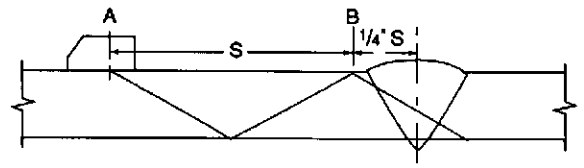


Figure 17—Weld Scanning

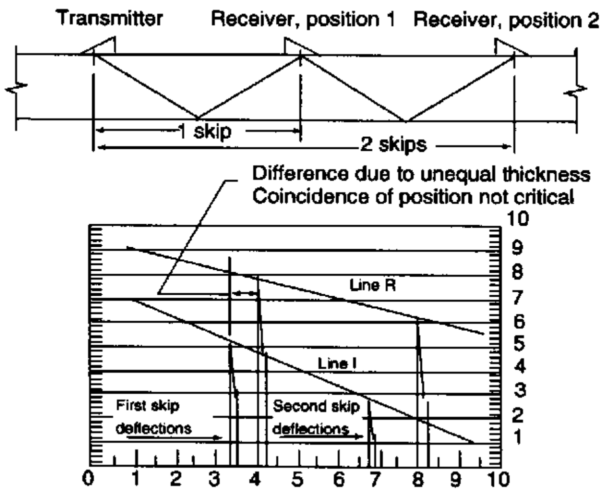


Figure 18—Transfer Correction Determination

skip distances. The echo signal amplitudes and metal path distances are entered on a graphical plot representing the CRT grid system. Without altering the instrument sensitivity, reflections are obtained at one and two skip distances on the member to be examined. All of the points are entered on the graphical plot. The peaks of each set of reflections are connected to produce a line R for the reference standard material and a line I for the material to be examined. These straight-line approximations are considered valid if the first skip distance is greater than 4 inches (100 millimeters). If the first skip distance is less than 4 inches, successive skip distances should be employed so that the first skip observed is 4 inches beyond the exit of the transducer.

c. The difference in amplitude between the two straight line approximations is noted at the greatest sound path distance anticipated during actual examination. The ratio of echo signal amplitude at the point is determined by dividing the upper value by the amplitude of the lower line. After determining the ratio of signal amplitudes, the amount of gain adjustment can be obtained from Table 3. When the R line is above the *I* line, the gain must be increased to ensure equivalent sensitivity in the member. When the *R* line is below the *I* line, the gain sensitivity must be decreased.

d. As an alternative to the procedure outlined in Items b and c, a distance amplitude correction (DAC) curve may be constructed to represent attenuation losses. To construct this curve, two transducers of like specifications (size, frequency, and angle) are assembled and used in a pitch-and-catch operation. The signal from the first full V-path of

Table 3—Transfer Correction Gain Adjustment

Ratio	db	Ratio	db
1.1 to 1	1	40 to 1	32
1.25 to 1	2	50 to 1	34
1.6 to1	4	63 to 1	36
2 to 1	6	80 to 1	38
2.5 to1	8	100 to 1	40
3.2 to1	10	125 to 1	42
4 to 1	12	160 to 1	44
5 to 1	14	200 to 1	46
6.3 to 1	16	250 to 1	48
8 to 1	18	316 to 1	50
10 to 1	20	400 to 1	52
12.5 to 1	22	500 to 1	54
16 to 1	24	630 to 1	56
20 to 1	26	800 to 1	58
25 to 1	28	1000 to 1	60
32 to 1	30	1250 to 1	62

sound travel on the reference calibration block is adjusted to approximately 90 percent of full screen height with the calibrated decibel control. The numerical value of the decibel is recorded, and the location of the peak on the screen is marked. The two transducers are moved apart and maximum screen indications of consecutive V-paths are marked on the screen. A "curve" is drawn along the points that have been marked on the screen, which creates a DAC capable of being used to compensate for transfer corrections.

e. To use the curve created in Item d, the same two transducers are utilized with pitch-and-catch techniques on the material to be inspected. The height of the echo signal from the first full V-patch is adjusted with the calibrated decibel control to align the maximum response with the DAC. The numeric value of the present decibel control and that which was documented during the DAC construction are compared and applied to the equation $A - B = C$. A is the decibel value of the curve on the calibration block, B is the decibel value of the curve on the test surface and C is the value of the decibel correction to be applied. Due to changes of attenuation values at interfaces with angle changes, the preceding procedure should be used during the actual inspection.

f. The two previously described techniques of determining transfer correction values are examples of methods that have been proven successful. The method of transfer correction should always be qualified to determine its accuracy. The operator's ultrasonic specialist should also verify the method.

7.8 DISCONTINUITY LOCATION

Accurate knowledge of the location of ultrasonic reflectors is necessary in order to differentiate between weld discontinuities and other reflectors, such as surface weld profile irregularities and root protrusions in single-sided weld connections. Further, the classification of flaw character and rejectability is strongly dependent on location, that is, root versus fusion zone versus interior of weld versus possible base metal lamellar tearing. The techniques of discontinuity location applicable to tubular member examination and weld examination in general are presented in the following sections.

Accurate location of reflectors in angle beam examinations is accomplished by a triangulation technique using sound beam angle, a measured surface distance to some reference point, and a sound path distance obtained form the potential scale of the cathode ray tube. The solution of triangulation problems can be resolved though use of special ultrasonic slide rules or electronic calculators. The utility of the special slide rules is found in examination of plate-to-plate and pipe-to-pipe butt welds but are of little value in examination of T, K, and Y connections. Electronic calculator solutions are applicable to all connections but require a basic working knowledge of trigonometry and are devoid of the graphical visualization desired by some UT personnel. The methods recommended herein are applicable to all connections, provide graphical visualization, and require little knowledge of trigonometry.

7.8.1 Graphical Plotting Cards

7.8.1.1 A graphical plotting card as shown in Figure 19 can be employed to determine the sound beam path in the member and provides all details required for a triangulation solution of discontinuity location. Preparation of the plot for examination of plate-to-plate and pipe-to-pipe butt welds will be presented herein in exact detail followed by a description of corrections for circumferential beam paths and elliptical scans encountered in diagonally intersecting tubular connections.

7.8.1.2 The thickness of the member obtained during the preparation for examination is shown on the plotting card by a line drawn horizontally to the upper scale at the distance equivalent to the measured thickness (see Figure 20). The sound beam path is represented by a line drawn through the zero point in the upper left-hand corner and the protractor angle of the normal incident beam angle obtained by the measurement described in Section 7.5.3.5. (This angle is not valid and cannot be used for circumferential beam paths and elliptical sections scans.) The construction line for the beam angle is shown in Figure 21. The simulated plot of reflection within the metal is completed by determining the skip distance and extending the plot between the top scale and the line representing the bottom surface of the member (see Figure 22).

7.8.1.3 The scale across the top of the card represents the position of the transducer at point Zero with respect to all other points in the member. To determine the length of the sound path at any point in the member, it is necessary to construct a second scale just below the horizontal line representing the bottom surface. It is important to note that the diagonal line which is drawn through zero to the bottom of the card is at all points a mirror image of the skip reflections between the two surfaces of the metal. With this consideration, a rule with the same scale divisions as that shown across the top of the graph is placed beside the diagonal line, and the distance along the line marked at spacings of 1/10 inch (2.54 millimeters) see Figure 23. By placing a straight edge vertically on the plotting card, each of these points is used to construct a scale below the bottom surface line which represents the sound path distance (see Figure 24). If the same scale of measurement is employed for calibration of the horizontal scale of the CRT. The distance from the zero point (transducer sound exit point) to a reflector can be determined directly from the scale at the bottom of the CRT.

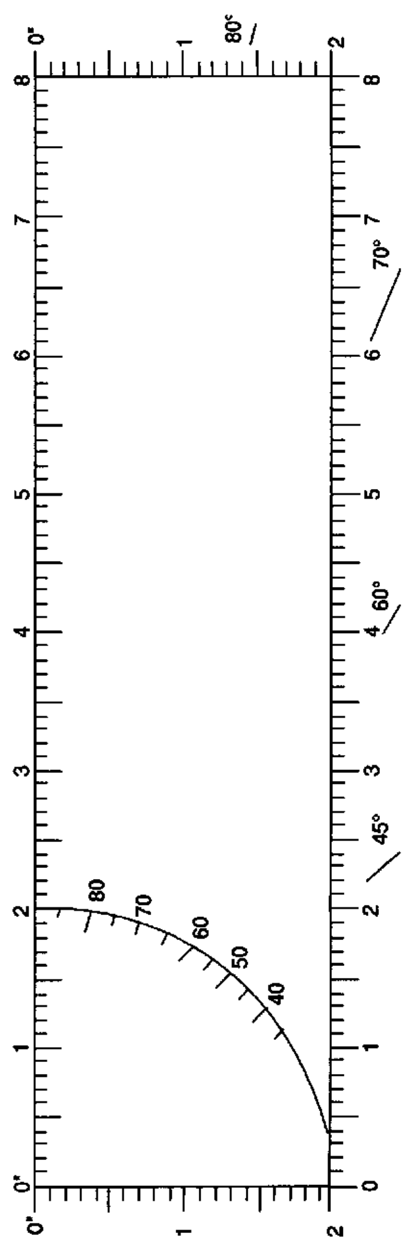


Figure 19—Graphical Plotting Cards Example 1

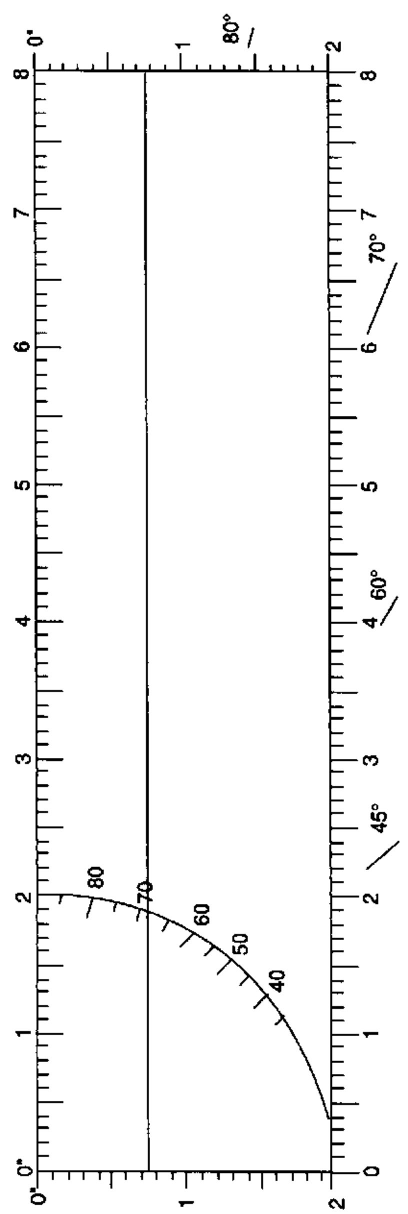


Figure 20—Graphical Plotting Cards Example 2

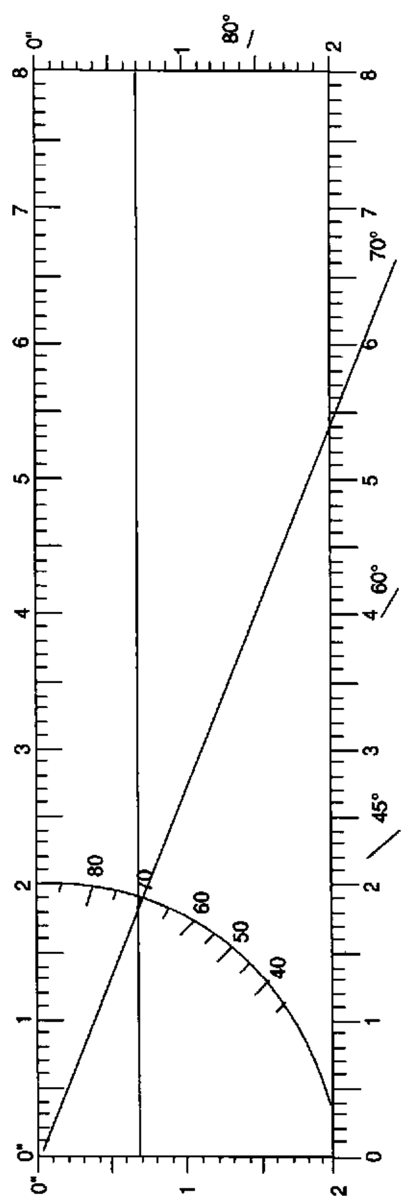


Figure 21—Graphical Plotting Cards Example 3

7.8.1.4 After the sound beam plotting card has been constructed, a plastic overlay or cursor is prepared using the known or anticipated weld geometry. On butt welds, a center line index can be employed as a reference to the edge of the root face indexed by the scribed line or punch marks placed on the member during preparation for examination. For diagonal intersection connections, the anticipated weld geometry is sketched, and the root face positioned at the predetermined distance from the punch index (see Figures 25 and 26). A profile gauge is useful for determining the local dihedral angle, pipe curvature, and weld surface profile. Several overlay sketches will be required to represent the changing weld geometry as one moves around the intersection weld in dihedral intersection connections.

7.8.1.5 To determine the location of a discontinuity, assume the weld shown in Figure 26 is being examined. In the scanning of the weld, an indication was observed on the horizontal scale of the CRT at a position of 3.8 inches (96.5 millimeters). The distance of the transducer from the line or punch mark index is noted, and the value marked on the upper scale. The plastic slide is then positioned on the plotting card at the measured punch mark distance from the probe exit point. The discontinuity is seen to lie on the near-fusion line and is located exactly 3.55 inches (90.17 millimeters) ahead of the probe

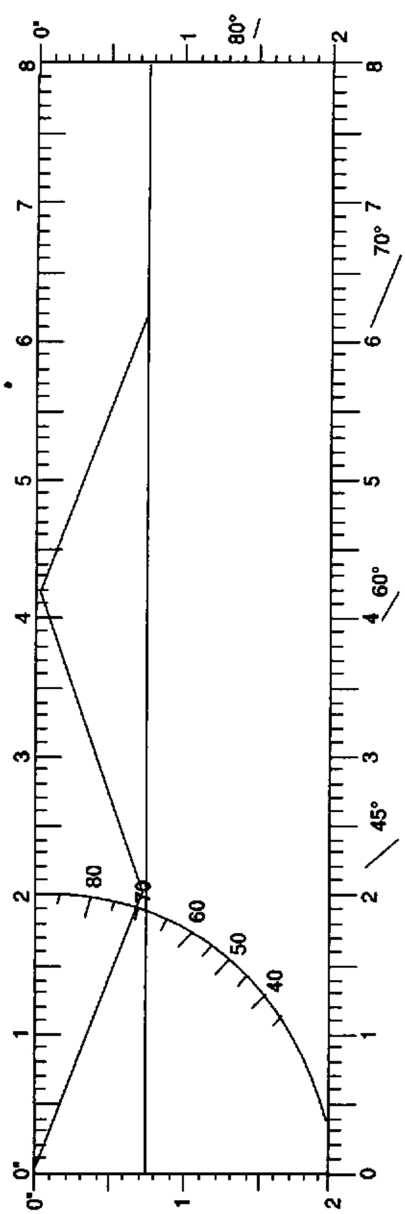


Figure 22—Graphical Plotting Cards Example 4

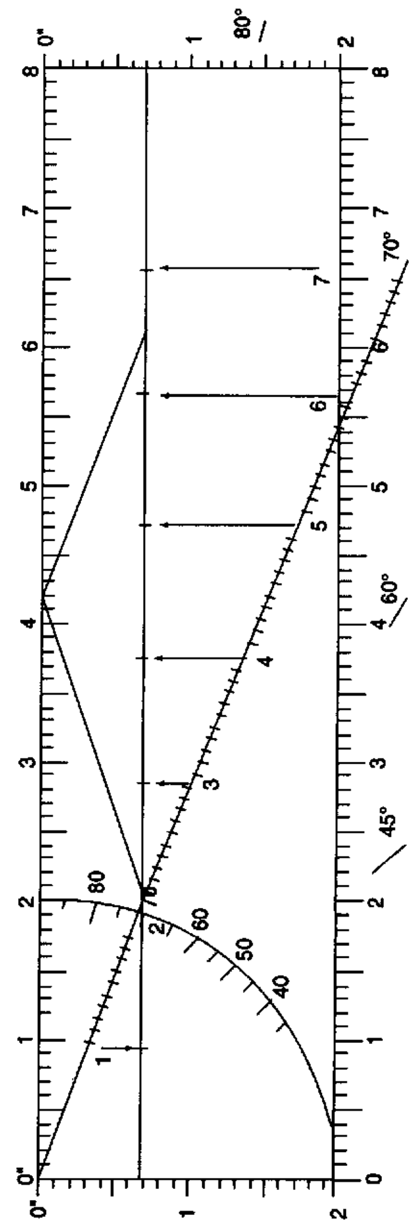


Figure 23—Graphical Plotting Cards Example 5

index mark and 0.2 inches (5.08 millimeters) below the surface of the member. Note that, in this example, the sound would not reflect from the surface at 4.1 inches (104.14 millimeters) but would continue in a straight path through the weld.

7.8.2 Correction for Circumferential Beam Path Scans

7.8.2.1 When scanning in the circumferential direction of a pipe for discontinuities in weld longitudinal seams, the skip distance and incident angle drawn on the plotting card are not the same as that for plate of the same thickness. Figure 27 illustrates the difference in the skip distance between a plate scan, SD_1, and the circumferential pipe scan, SD_2. The difference in length between the two is a function of the diameter and the wall thickness of the pipe. Figure 28 is a plot of normal incident angles for various thickness/diameter ratios and provides a multiplying factor to determine the increase in length of the skip distance from flat plate. Alternatively, the technique described in Section 7.8.3.2 may also be utilized.

7.8.2.2 The preparation of a plotting card for the circumferential scan follows the same procedure as for the flat plate or pipe-to-pipe scans except the skip distance and

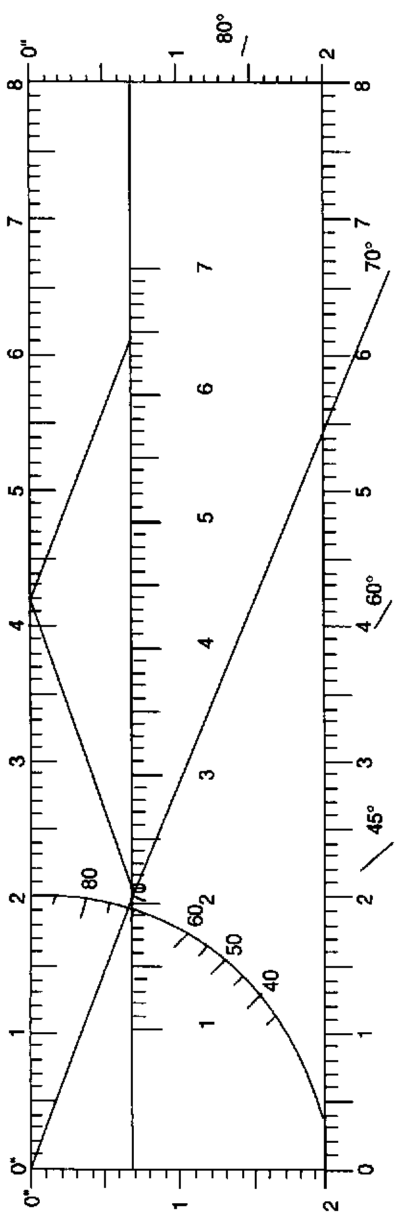


Figure 24—Graphical Plotting Cards Example 6

angle must be determined from the information in Figure 28 and not by use of the protractor on the plotting card. For example, assume the pipe was 20 inches (508 millimeters) in diameter and the wall thickness was 1 inch (25.4 millimeters). The skip distance in flat plate for a 60-degree probe determined by construction of a plotting card is found to be 3-½ inch (88.9 millimeters). Consulting Figure 28, the thickness/diameter ratio of 0.05 (1 divided by 20=0.05) is found to intersect the 60-degree curve at 1.42 on the skip distance multiplier scale. The actual skip distance in the 20-inch (508 millimeter) pipe with a 1-inch (25.4-millimeter) thick wall is therefore 3.5 multiplied by 1.42, or 4.97 inches (126.24 millimeters). This skip distance is inserted on the plotting card (see point B, Figure 29). One half the skip distance of 2.5 inches (64 millimeters) is plotted as point C. Point D is the point of reflection on the inside diameter of the pipe. The effective beam angle, *θ*, is determined by drawing a line from A through D and reading the point of intersection on the arc of the protractor. For this example, the 60-degree probe produces an effective angle of 68-degrees. A notation of these effective beam angles is important when conducting examinations for defects which may be perpendicular to the surface of the pipe since an effective angle of 60 degrees would produce the same mode conversion in the pipe as that experienced with a 60-degree probe on flat plate. The remainder of the plot preparation is achieved in the same manner as that for flat plate.

7.8.2.3 The skip distance in flat plate can be determined without the necessity of construction on the graphical plot by multiplying the thickness of the member by a geometric factor unique to each probe angle. The factors or numbers are shown here and are found engraved on the wedge of some angle beam probes:

Probe angle, degree	45	60	70	80
Skip distance factor	2	3.5	5.5	11.5

Thus the skip distances for ½ inch (12.7 millimeter) thick plate for the angles of 45, 60, 70, and 80 degrees would be 1.0 inch, 1.75 inches, 2.75 inches, and 5.75 inches (25.4 millimeters, 44.45 millimeters, 69.85 millimeters, and 146.05 millimeters) respectively.

7.8.2.4 When consulting Figure 28 for the skip distance multiplying factor, note that the vertical line representing the thickness/diameter ratio many not cross all of the probe angle lines. This indicates that the angles which do not intersect the t/D ratio will not produce a central beam angle that intersects the back wall of the pipe. Those angles cannot be employed to examine for discontinuities near the inside surface and are to be used only for scanning to the depth representing a thickness that produced a t/D ratio intersecting the probe angle line.

7.8.3 Correction for Elliptical Scans

7.8.3.1 When scanning for discontinuities in T, K, Y connections, the section through the pipe along the centerline of the beam is elliptical, and the skip distance of the sound beam lies somewhere between that of a flat plate and the circular section of the circumferential scan. At toe and heel (0-degree cant angle as defined in Figure 14), the skip distance converges to the flat plate case. A series of graphical plots such as Figure 28 could be prepared for determining the correction required to construct a plotting card of the sound path; however, the number of different combinations of thickness, diameter, and angular intersections encountered in construction would necessitate a large number of graphs and would become too cumbersome for use in field examinations.

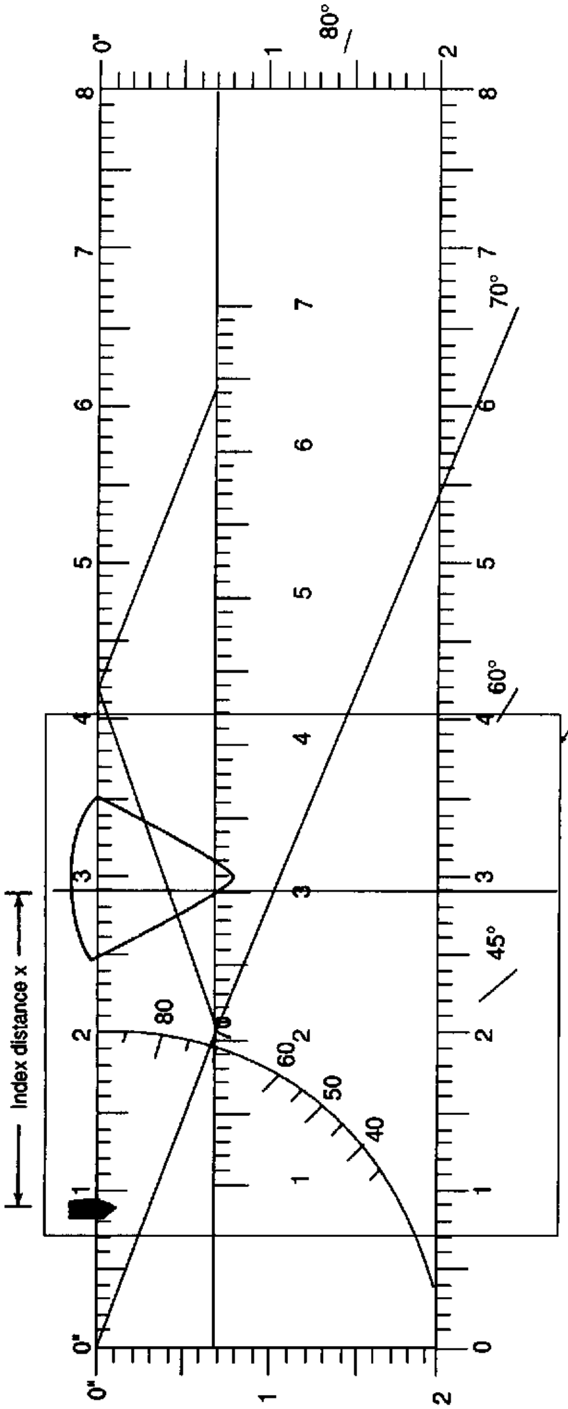


Figure 25—Graphical Plotting Cards
Example 7

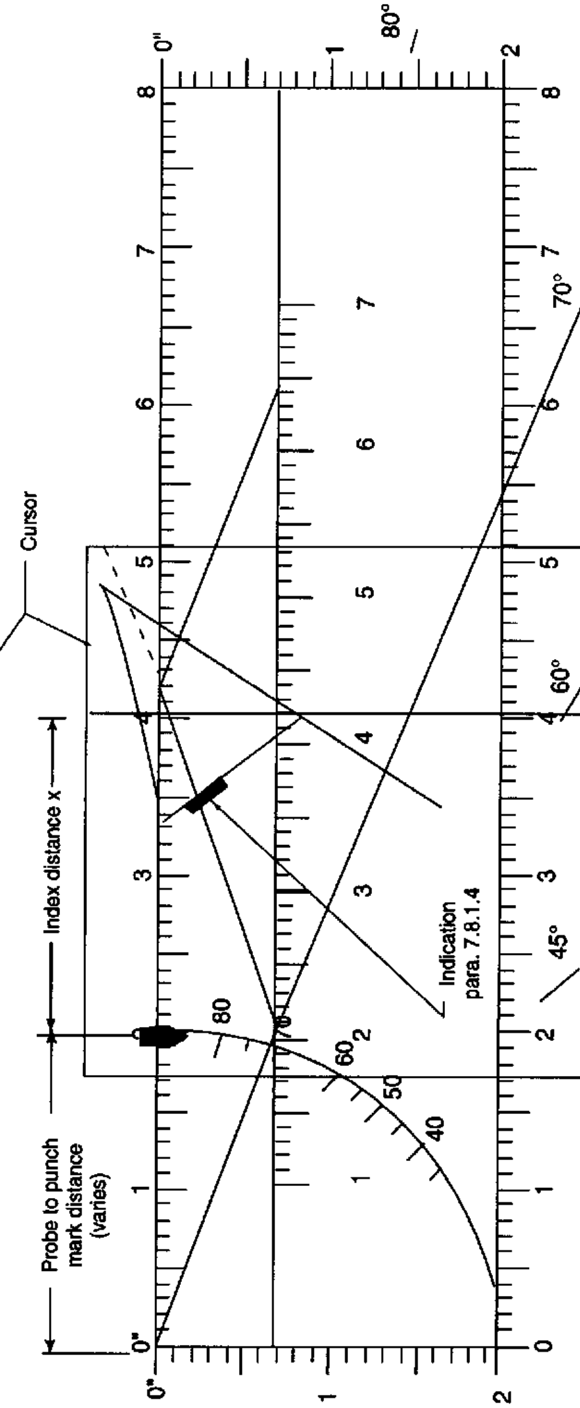


Figure 26—Graphical Plotting Cards
Example 8

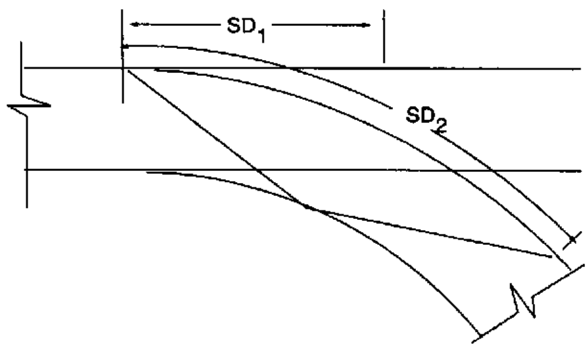


Figure 27—Circumferential Beam Path Scan

7.8.3.2 In lieu of graphical solution of the skip distance correction for the elliptical scan, the actual skip distance can be determined by measurement. Using two probes of the same angle, one as a transmitter and the other as a receiver, the distance between probe exit points is measured when the signal from the transmitter is maximized on the CRT (see Figure 30). The skip distance obtained is drawn on the plotting card in the same manner as with the circumferential scans, and the remainder of the plot is completed in the same manner. The effective angle is again determined by the intersection of the line A–D with the arc of the protractor.

7.8.3.3 The construction of separate plotting cards for each elliptical case is not generally required unless a discontinuity has been detected which requires careful evaluation. In many cases, it will suffice to interpolate between the flat plate case (0-degree cant angle) and the circular case (90-degree cant angle). When a specific graphical plot is required, it is imperative that the two transducers be oriented on a line at the dame cant and skew angles as the probe was when the discontinuity was detected. Assurance of proper orientation can be achieved by drawing a straight line through the center of the scan path when the discontinuity is detected and using the line to position the two transducers during the skip distance measurement.

7.8.3.4 Another method of determining the corrected beam angle is to use the distance between the index points in the following equation:

$$TAN\ \theta = \frac{A-B}{2 \times T}$$

Where:

θ = effective beam angle.
T = material thickness.
A–B = distance between index points as depicted on the plotting card in Figure 29.

The metal path distance taken from the screen may also be used to determine the effective beam angle by using the following equation:

$$COS\ \theta = \frac{2 \times T}{M}$$

Where:

θ = effective beam angle.
T = material thickness.
M = metal path distance taken from the screen.

7.9 DISCONTINUITY EVALUATION

Evaluation consists of the various steps required to assess the unknown character, orientation, and size of discontinuities whose presence has been established during scanning. Characterization and orientation are reasonably reliable determinations of a well-executed ultrasonic examination. Size determination is more difficult, particularly in dimensions of interest to a fracture mechanics analysis. The methods of evaluation are described in the following sections, including three recommended methods of reflector sizing.

7.9.1 Characterization

7.9.1.1 The basic geometrical discontinuity shapes which can be identified by ultrasonic beam manipulations are cylindrical, spherical, and planar. Weld imperfection geometries corresponding to the cylindrical shape are hollow beads, some slag lines, and unfused slugs. Single pores and widely spaced porosity produce reflections similar to the ideal spherical reflector. The group of weld imperfections identified by planar configurations are lack of fusion, unfused root faces, fusion line slag, undercut, and cracks. Characterization of discontinuity types beyond cylindrical, spherical, and planar should not be attempted.

7.9.1.2 The reflection from a spherical discontinuity remains essentially unchanged when observed from any direction. Identification is achieved by manipulation of the probe as shown in Figure 31. The amplitude from this type reflector is often small at the scanning sensitivity because of the small reflecting area presented to the sound beam.

7.9.1.3 If the same manipulations employed for spherical reflectors are applied to planar reflections, the results are as shown in Figure 32. Movement of the probe laterally while maintaining position No. 1 may result in a varied or constant amplitude but continuity of signal will denote the reflector has definite length.

7.9.1.4 To differentiate the cylindrical reflector from the planar, it is necessary to employ several different angles. If the reflector produces equivalent reflections at all angles of incidence after applying the tests for the planar reflector, it can be assumed to be cylindrical in shape. A significantly greater amplitude from a single angle of intercept would denote a planar reflector.

7.9.1.5 The analysis becomes somewhat more difficult when the reflector displays characteristics of more than one

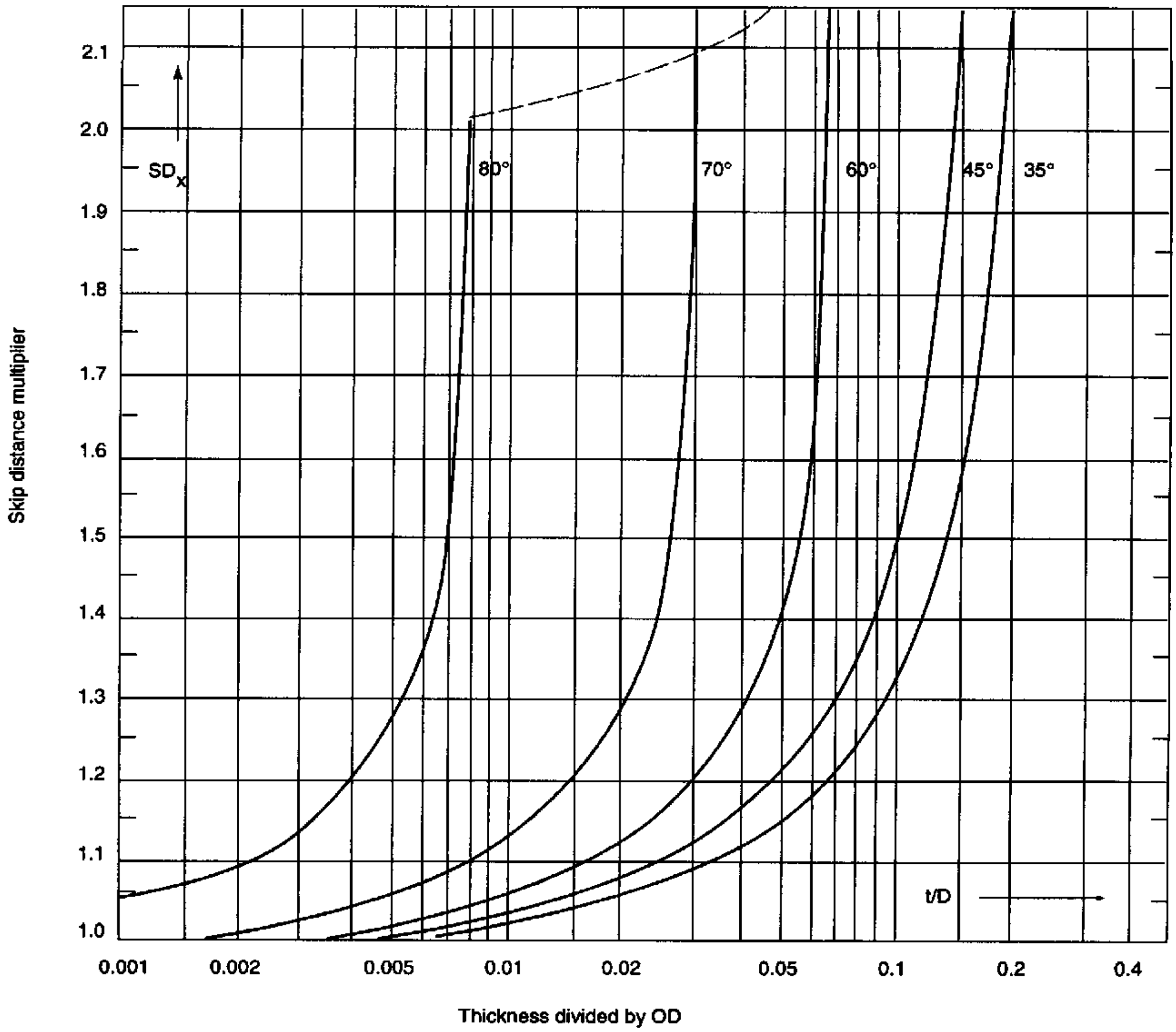


Figure 28—Skip Distance Adjustment for Circumferential Beam Path

geometry, as visualized by a large irregular slag inclusion lying along a fusion boundary. If reflectors of this type are observed and the size exceeds the acceptance criteria, the safe approach is to classify the discontinuity as indeterminate and evaluate it as a planar type.

7.9.2 Orientation

Longitudinal orientation of a reflector is obtained principally by manipulation of the probe. The orientation of the long axis of planar and cylindrical reflectors is determined by maximizing the indication on the cathode ray tube. This indicates the orientation of the reflector as being in a plane perpendicular to the sound beam axis. Maintaining a maximum amplitude while scanning the length of the reflector reveals any changes of orientation. These changes should be noted and reported for use in evaluation.

Determining the approximate orientation of planar reflectors in the transverse or short dimension is achieved by observing the reflector with different angles in the same manner required to separate planar from cylindrical reflectors. The angular orientation of the planar face is that nearest to being perpendicular to the sound beam axis of the probe yielding the greatest amplitude.

7.9.3 Size Evaluation

Several methods have been derived for determining the size of reflectors, unfortunately, none appear to yield absolute results in the examination of T, K, and Y connections of tubular structures despite satisfactory results on plate and pipe butt welds. Three methods which produce useful information on sizing are recommended for use on offshore structures. These are as follows:

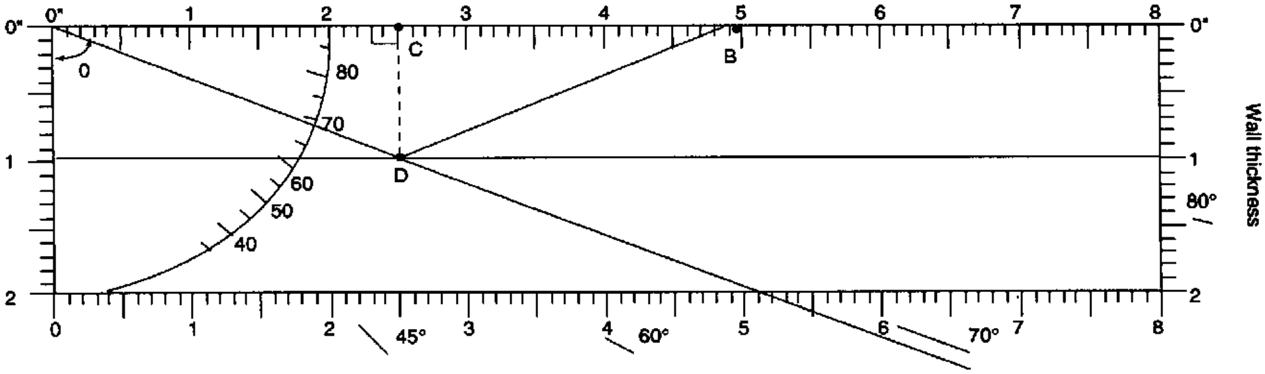


Figure 29—Graphical Plotting Card for Circumferential Beam Path

a. The amplitude comparison technique.
b. The beam boundary intercept technique.
c. The maximum amplitude technique.

In some instances, it will be necessary to employ all three using best judgment for the final estimation of size. However, if the reflector is large with respect to the sound beam, the methods of sizing will generally be restricted to the beam boundary intercept and maximum amplitude techniques. When using either of these two techniques the operator should be aware that the accuracy of the measurements is affected by the beam width of the transducer being used. Transducers used for detection purposes are designed to have a significant amount of beam spread so that slight misalignment relative to the reflector will not hamper detection capabilities. However, these transducers are less accurate when used for estimating the actual dimensions of a reflector. In general, a reduction in beam spread or width will result in more accurate length or height measurements. In addition, a smaller beam width will improve multiple-reflector resolution where numerous small indications can otherwise appear as one continuous discontinuity. Beam width can be reduced by using higher frequency transducers. When thin materials are being examined, a combination of higher frequency and reduced element size can be used. Use of these transducers will minimize reflector rejection when beam width, rather than reflector length is measured, (this can occur when reflector size is less than beam diameter). Higher frequency transducers should be used only for discontinuity sizing and not for discontinuity detection. Alternatively, careful use of beam boundary or maximum amplitude techniques will show if a reflector is significantly smaller than the cross section of the sound beam.

7.9.3.1 The Amplitude Comparison Technique

The amplitude comparison technique can be described as follows:

a. Size determination by the amplitude comparison technique is achieved by comparing the discontinuity reflection to the reflection obtained from an artificial reflector in reference blocks of the types described in Section 7.10.4. If the reflections are equivalent and the sound path distance the same, the areas of the two reflectors intercepting the sound beam are considered equal. In order to improve the accuracy of sizing of weld discontinuities, which generally are elongated parallel to the weld length, a multitude of artificial reflectors of various widths and lengths should be available for comparison with the discontinuities detected during scanning. Selection of the proper length artificial reflector requires prior determination of the length of the unknown by one of the alternate methods of sizing.
b. Since the amplitude of a reflector diminishes with increased distance from the probe, it is necessary to construct a DAC curve for reflector comparison when the unknown reflector fails to fall at the same distance on the display-screen horizontal scale as the reference reflector. The DAC is constructed by observing the response of one or more reflectors of the same dimensions and plotting the peak amplitude for each point of observation. A line drawn through these peaks represents the amplitude expected from a reflector of the same size at any distance from the probe. See Figure 33.
c. The difference in the curvature between the reference reflector and the member being examined, the roughness of the surfaces, and variations in coupling conditions or acoustical properties introduce errors in sizing by the amplitude technique. To minimize these errors, a transfer correction in sensitivity as described in 7.7.4 is mandatory.
d. The effect of varying the instrument controls on the shape of the distance amplitude curve must be considered when employing the amplitude comparison method. Reject and dampening should be used only during the initial calibration when required to achieve clarity on the display screen. After establishing the DAC curve, the calibrated gain control (attenuator) is the only instrument setting which may be varied and solely for purposes of transfer correction.

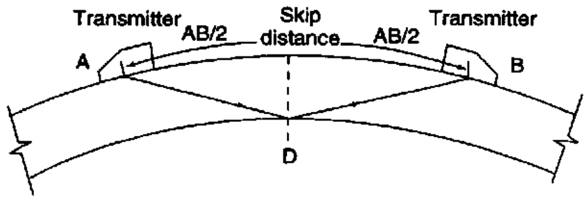


Figure 30—Alternate Method for Determination of Skip Distance on Current Surfaces

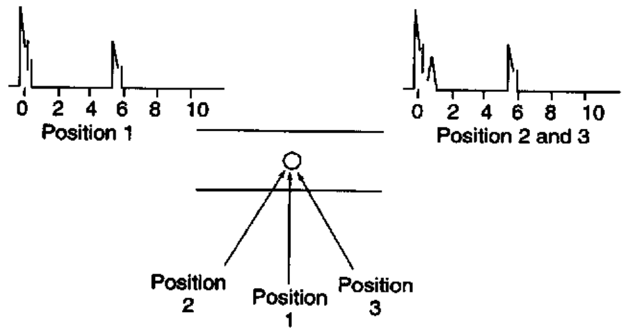


Figure 31—Probe Manipulation for Spherical Discontinuity

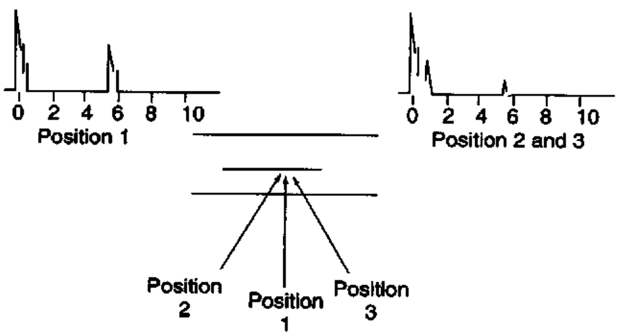


Figure 32—Probe Manipulation for Planar Discontinuity

e. The use of a single reference reflector together with attenuation adjustments is not considered as accurate as the method just described and is not recommended.

f. In estimating the dimensions of a reflector by the amplitude comparison technique, the area of the reference reflector must be known, and the shape must be similar to that expected of the flaw. Assuming a ⅛ inch (3 millimeter) flat-bottom hole is to be used as standard, the area is 0.012 inch². This is obtained by pure geometry:

$$A = 3.14r^2$$

When the flat-bottom hole is used as a reference, the result can be correlated only to round areas if reasonable accuracy is to be expected. Unfortunately, weld defects of interest are not of this shape and do not produce the same response as round reflectors. Nevertheless, if the assumed

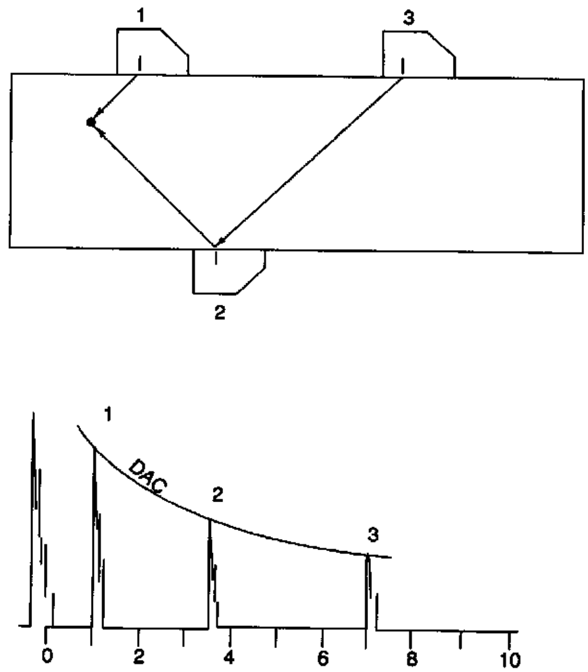


Figure 33—Distance Amplitude Correction

example is continued and the unknown reflector proved to be 6 decibels greater in response than the reference, the area of the unknown is assumed to be twice as large as the reference reflector or 0.024 inch². Therefore:

$$A = 0.024 \text{ inch}^2 = 3.14r^2$$

Solution of the problem yields a radius of 0.083 inch, and the unknown is assumed to be a circle of 0.166 inch diameter.

g. For weld root examinations, machined notches should be employed since they more nearly represent actual weld discontinuities. Assuming again a specific calibration standard, the dimensions of a discontinuity are estimated as follows: With a reference standard notch 0.0625 inch by 1 inch, the area is obtained by multiplying the length by the width to obtain 0.026 inch². Assume also that the unknown is a corner reflector, the same as the reference, and its length has been determined by another method to be 0.500 inch. Although not very accurate, the width of the unknown is estimated by dividing the reference area by 0.500 inch to obtain a width of 0.125 inch.

h. The extent of error in the above illustrations will depend on the size of the probe employed and the distance of the reflectors along the sound beam path. The inaccuracy is considered too great to qualify a procedure meeting the minimum standards recommended herein if the comparison technique is to be the sole method employed. For internal planar reflectors, the amplitude comparison technique is further handicapped by the large effect of small misorientations relative to the beam axis. Except for sizing small round reflectors and estimating the width of long lack-of-penetration in single-sided welds and long thin reflectors which exceed the beam width, the amplitude comparison method offers little help in dimensional sizing of weld defects. Solution of the latter two problems is possible because the sound beam intensity is concentrated at the center of the sound field and is responsive to width changes when the length of the reflector is greater than the width of the beam. Even then, accuracy diminishes rapidly when the reflector width exceeds approximately ¼ inch (6.4 millimeters).

7.9.3.2 Beam Boundary Intercept Technique

The beam boundary intercept technique is utilized as follows:

a. Determination of the transverse dimension of a reflector by the beam boundary intercept technique is accomplished by manipulating the probe to obtain the maximum signal from the reflector and adjusting the echo signal to some convenient screen height, for example, 75 percent of full scale. The sensitivity is then increased 20 decibels using the calibrated gain control and the probe moved forward until the echo signal returns to the original maximized value, that is, 75 percent of full scale. At this point, the bottom edge of the 20 decibel beam boundary determined by the procedures outlined in Figure 10 will be intercepting the top edge of the reflector (see Figure 34). Then one should carefully record the beam path distance on the calibrated horizontal scale of the display screen and the distance from the probe zero index to the point on the weld (scribe line, punch marks, weld centerline, and the like).

b. The bottom of the reflection is located by moving the probe backward through the maximum position until the echo signal again returns to 75 percent of full screen indicating that the top of the 20 decibel beam profile is intercepting the bottom edge. Again, one should record the sound path and surface distance of the probe from the weld. The transverse width then can be determined subtracting the differences in the depths of the top and bottom from the surface as determined on the plotting card. The process can be simplified by plotting the beam profile directly onto a plotting card and extracting the top and bottom intercept points directly from the vertical scale on the left side of the card (see Figure 35).

c. The length of a reflector is determined in the same manner by moving parallel to the reflector and noting the points where the intensity diminishes 20 decibels from the maximum. The length is determined by measuring distance between the centerline of the probe positions and subtracting the sum of the half-beam widths (determined in 7.5.3) at the distance of the intercept.

d. The technique of increasing the sensitivity by 20 decibels while at maximum sensitivity and translating to a distance which produces the original maximized signal reduces the error resulting from vertical non-linearity in the instrumentation. Manipulation of the probe until the vertical echo signal drops to ¹⁄₁₀ of the scale height (20 decibel ratio) can be employed if the vertical circuits are known to produce exact

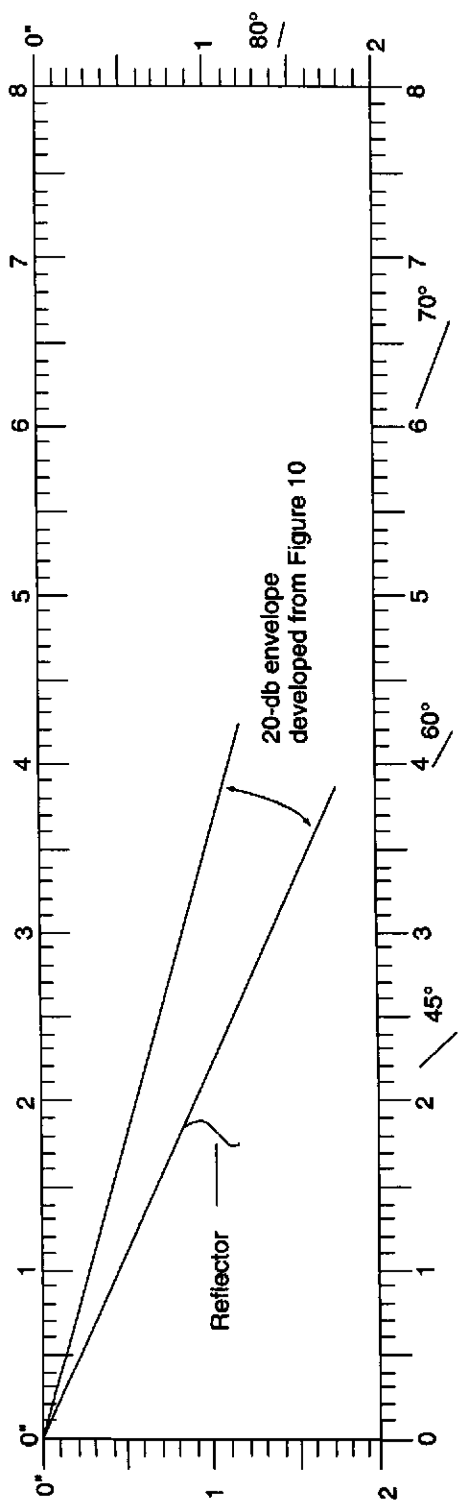


Figure 34—Beam Boundary Technique

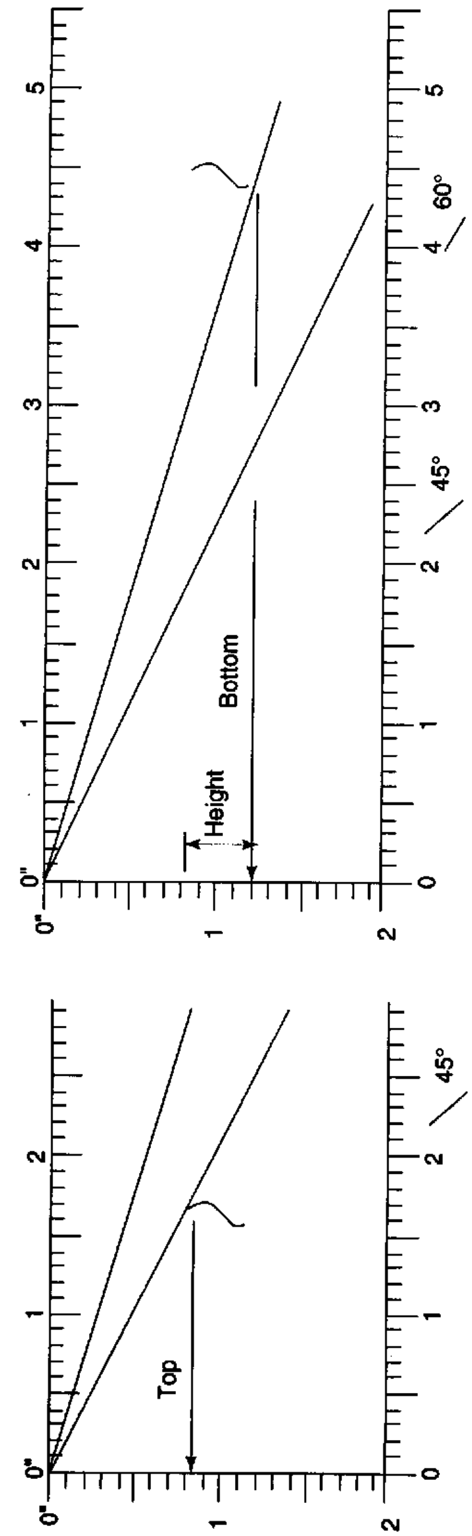


Figure 35—Beam Boundary Plotting

ratios; otherwise, significant errors will be added to the determination.

e. The beam boundary intercept technique is best suited to members approximately ¾ inch (19 millimeters) and thicker and evaluation on the first traverse (half skip) of the thickness. Multiple determinations should be obtained from the edges of the reflector in order to minimize errors due to coupling variations and contact pressure. At least three attempts should be made for each edge, and the results for all three should fall within ¹⁄₁₆ in. (1.6 millimeters) of the same location. The method yields uncertain results when applied to measuring the depth of corner reflectors, such as lack of penetration in single-sided welds. Alternate methods are suggested for that type of reflector.

f. When reflectors lie at orientations other than perpendicular to the scanning surface, the measured transverse dimension will represent only the vertical component of the reflector. In most cases, this is the dimension perpendicular to the applied stress and is the value desired for fracture mechanics analysis of criticality; however, to permit engineering evaluation of the effect of orientation on fracture safety, it is advisable to report the actual width dimension and orientation by graphical determination on the plotting card.

7.9.3.3 Maximum Amplitude Technique

The following gives details for the maximum amplitude technique.

a. The maximum amplitude technique utilizes the fact that most of the energy in the ultrasonic beam is concentrated near the center of the beam in a very narrow band. This characteristic is employed to find the top of reflectors by maximizing the reflection as in the beam boundary technique and moving the probe forward until the echo signal just begins to drop from the peak value. The bottom edge is determined by moving the probe backward until the echo signal just begins to drop. Measurements of the sound beam path lengths, D_1 and D_2 (see Figure 36), and surface distances for each probe position are entered onto the plotting card to determine the width of the reflector.

b. The length of a reflector is determined by moving the probe parallel to the reflector until the maximum amplitude begins to decay. The length is determined from the centerline of the transducer at one extreme to the centerline position at the opposite extreme.

c. Some discontinuities exhibit a number of reflections lying at random depths and orientations from the probe; others are single smooth planes of reflection. The edges of the first type are indicated when the last full reflection of a group begins to decay, and the sound path distance is determined from the assumed left-hand edge of the reflection on the CRT (see Figure 37). For smooth reflectors, the edges are determined by moving past the end of the discontinuity until the reflection drops to zero, then returning until the reflection just reaches its maximum.

d. Best results from the maximum amplitude technique occur when the instrument pulse length is very short and the probes have high-resolution capabilities. Probes of a high diameter-to-wave-length ratio produce a sharply defined central beam and are preferred for this technique. These conditions dictate the use of frequencies above that for normal scanning and the largest practical diameter for the surface conditions of the examination. Probes with a frequency of 4 megahertz and diameters of ½ inch (12.7 millimeters) or larger are recommended. Caution must be exercised to avoid evaluation in the near-field when employing probes with these characteristics. This technique also is difficult to apply to corner reflectors.

e. Alternative techniques may be utilized when qualified by the operator's ultrasonic specialist. A commonly used adaptation to 7.9.3.3, Item a is to multiply the sound path travel distance by the cosine of the transducer angle to determine reflector width. This technique can also be used to determine the diameter of cylindrical shaped defects. To do this, one should adjust the vertical height of the initial CRT indication to a convenient viewing height (75–80 percent of full screen height). The transducer should be moved forward toward the weld being inspected until the CRT indication begins to fall. The first sound path travel distance, A, can then be read from the bottom horizontal of the CRT and used in the following equation. The second sound path travel distance, B, is obtained by moving the transducer back, away from the weld being inspected, until the CRT indication has risen to its maximum and begins to fall again. The width, E, of the indication can then be calculated using the following equation where C is the angle of the transducer (see Figure 36).

$$E = COS(C) \times (B - A)$$

7.9.3.4 Inaccuracies in Size Elevation

The following should be noted concerning inaccuracies in size elevation:

a. All three of the described techniques are capable of yielding accurate results on flat plate weld examinations within the limitations described, but all three suffer significant loss of accuracy when examining tubular members. In the absence of a large number of curved-reference standards of the same geometry as the members to be examined, the accuracy of all techniques diminish due to a spreading of the beam at the coupling interface and the opposite curved wall of tubulars. The inherent broadening of the beam results in reduction of the centerline intensity and alteration of intensity to the beam edge. The magnitude of the error increases with the difference in diameters between reference and examined member.

b. When scanning in the circumferential direction or at a cant angle to the pipe axis, the sound beam also changes dimensions depending on the area of contact and the thickness-diameter ratio of the member. Figure 38 illustrates the increase in divergence after the beam has struck the back wall of a tubular during a circumferential scan. The effect is to alter the angular position of the 6-decibel, 20-decibel, or any other constant intensity ray of the beam. This invalidates the beam intercept technique and diminishes the accuracy of the amplitude comparison technique. The apparent change in incident angle described in 7.8.2 during circumferential and elliptical scans will invalidate that technique if the corrections are ignored. When possible, the size measurements should be made in the first half-skip distance of the sound beam to minimize the effects of beam spreading at the intercept with the back wall.

c. The popular method of determining the length of reflector by defining the ends when the CRT echo signal has dropped to half (6 decibels) results in an overestimation of reflector length if the length of the reflector is less than the cross sectional width of the sound beam. This error can be reduced by using a 20 decibel drop and subtracting the 20 decibel half-beam widths as discussed in 7.9.3.2, Item c (see Figure 39). This will still lead to a slight overestimation because the beam spread has been derived from a linear and not a point reflector. However, the 20-decibel beam profile is very near the extreme edge of the beam, and the error is small.

d. Errors in the length measurements in tubular members can result solely from the position of the reflector within the tube wall. Figure 40 illustrates the difference in length obtained by the intercept method from two equal-length reflectors located at different depths from the scanning surface.

7.9.3.5 Recommended Techniques

In practice the three sizing techniques should be performed in an organized sequence from simplest to most difficult usually in the following order. First, the amplitude comparison technique should be performed during initial characterization and orientation assessment with the discontinuity compared to known size implants. The maximum amplitude technique can usually be performed concurrently while the discontinuity remains at the maximized amplitude. The beam boundary technique should be performed if there is uncertainty in the previous sizing estimates or if characterization and orientation suggest using this technique.

The amplitude comparison technique is recommended for evaluating corner reflectors if the anticipated width is not much greater then ⅛ inch (3.2 millimeters). Length should be approximated by the maximum amplitude technique. For all other circumstances, all possible means should be employed. From the results, a best estimate should be offered with considerations to the effects of curvature and configuration.

7.10 ACCEPTANCE CRITERIA

Three levels of acceptance criteria are applicable to offshore structural fabrication as described in the following. The operator's ultrasonic and engineering specialists should

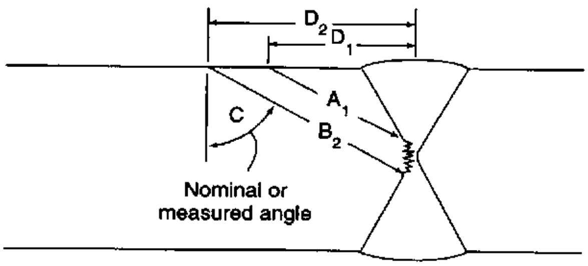


Figure 36—Maximum Amplitude Technique

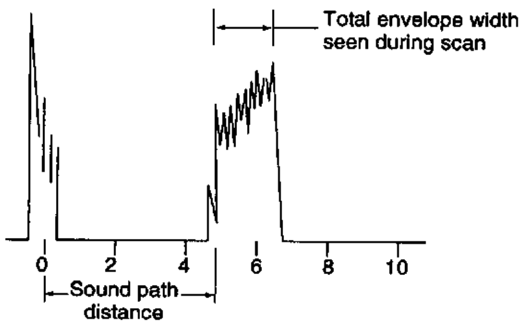


Figure 37—Multiple Reflectors

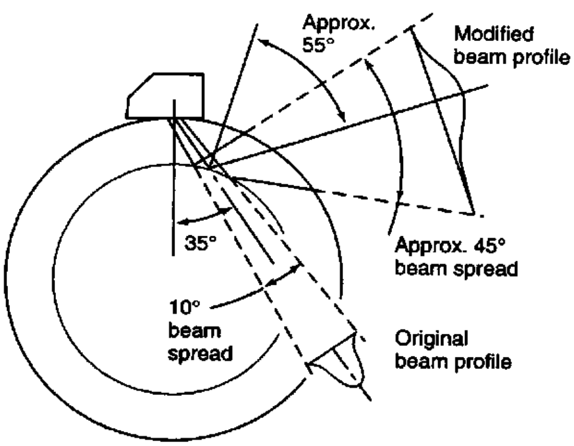


Figure 38—Circumferential Direction Beam Profile

determine which of these acceptance levels are consistent with the design assumptions:

a. Level A—Workmanship quality—is not inherently related to the component's fitness-for-purpose, but instead based upon the quality of weld that a welder should be able to achieve routinely and upon the ability of the examination method to detect discontinuities. This level should always be utilized for critical structures designed and constructed with unspecified fracture-controlled materials. Level A is applicable to tubular T, K, Y connections and butt joints in tubular, plate girder, beam, shape, and plate connections.

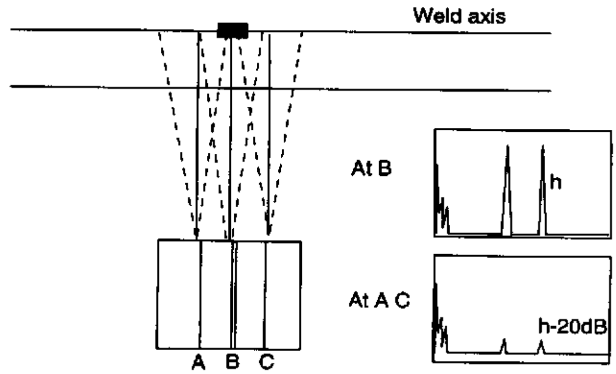


Figure 39—20-Decibel d/B Beam Boundary Method

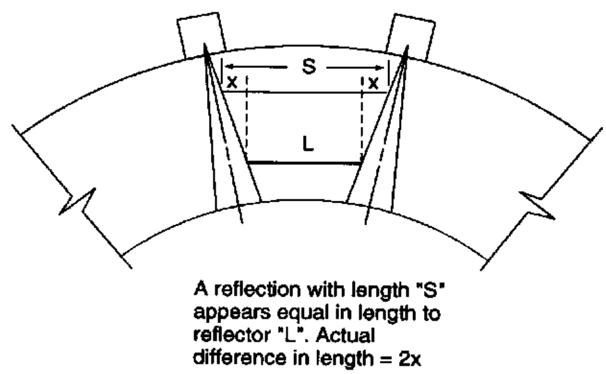


Figure 40—Length Measurement Comparison

b. Level C—Experience-based fitness-for-purpose quality—is based upon generalized consideration of fatigue, brittle fracture, and tensile instability modes of failure, and intended for use in applications where the design stress, fatigue analysis, and minimum toughness meet the requirements of API Recommended Practice 2A-WSD. This also requires consideration of the fracture toughness of welds and heat-affected zones.

c. Level F—Specific fitness-for-purpose quality—based upon specific analysis of fatigue, brittle fracture, tensile instability, and any other potential failure modes for a specified component or class of components in a specific application. This option provides a more technically complete approach for the particular application, and the fact that a more thorough investigation has been substituted for conservative assumptions implies that the derived flaw sizes may be accepted without compromising safety.

The appropriate level of examination is an integral part of the overall fracture control plan, which maintains a quality level consistent with the design performance. For example, Figures 41 and 42 show weld surface profile qualities and fatigue S-N curves which are consistent with each other. The three levels of ultrasonic acceptance criteria are based on a similar fatigue consideration. In bridge design, surface grinding and Level A internal examination are required to qualify for fatigue performance Level B (per AWS D1.1, Section 9). For offshore platforms designed to fatigue performance Level C (curve X), with as-welded surface profiles, Level C provides a compatible internal examination criteria. The fatigue curve shown for Level F would permit substantially larger flaws; however, in the specific fitness-for-purpose application, the actual fatigue criteria and flaw sizes would be related by analysis.

7.10.1 Level A Acceptance Criteria

The following applies concerning Level A acceptance criteria:

a. Level A corresponds roughly to workmanship standards specified in traditional codes developed for radiography. This level may be appropriate for welds whose surface profile is ground smooth and protected against corrosion in order to improve fatigue performance (for example, curve A in Figure 42 or for critical welds whose sole failure would be catastrophic, (that is, no redundancy) and where a low level of notch toughness prevails. The latter can be avoided with good welding practice and proper selection of materials.

b. Evaluation of reflectors based on amplitude shall include suitable adjustments for transfer effects (including surface roughness, contact area acoustical attenuation) and distance amplitude corrections, and shall be based on the peaked signal, as explained in following sections of this recommended practice. However, in view of the non-productibility of amplitude readings, precise numerical correction for all of the foregoing effects may not always be possible. Acceptance shall be based on the classification and length of the reflector and not upon arbitrary signal amplitude criteria alone.

c. The reference level calibration reflector is the side of the 1/16 inch (1.6 millimeter) diameter hole in the reference block for Level A examination (Figure 43), or a similar block designated by the governing specification.

d. All reflectors 6 decibels smaller than the reference level (that is, 50 percent DAC) may be disregarded. Reflectors above the 50 percent DAC line shall be further evaluated as follows, using techniques described in this recommended practice:

1. Classification as to the following:
   Spherical (point) reflectors.
   Cylindrical (linear) reflectors.
   Planar reflectors.
2. Length along the weld axis.
3. Location with respect to the weld cross section.

e. Isolated, random, point reflectors are acceptable. Aligned point reflectors shall be evaluated as linear reflectors.

f. Clustered multiple reflectors with indications above the 50 percent DAC curve should not exceed 1/3 of the branch thickness or 3/8 inch (9.5 millimeters), whichever is less, in any linear inch.

g. Linear or planar reflectors whose lengths do not exceed the limits of Figure 44 are acceptable, except as outlined below. Any reflector thought to be a crack jack of fusion, or lack of penetration (planar) based on the judgment of highly skilled experienced and qualified UT personnel should be brought to the attention of the operator. (Figure 44 is a composite of AWS and ASME criteria.)

h. Reflectors within the base metal of the main member (joint can) at welds shall be evaluated as described in the following. In addition, any such reflector that exceed the disregard level shall be reported to the operator.

1. Individual reflectors exceeding the limits of Figure 45 are rejectable.
2. Accumulated reflectors exceeding 8 percent of the area under the weld in any 6-inch (150-millimeters) or D/2 length (whichever is less) are rejectable.
3. Rejectable base metal reflectors shall be reviewed by the operator prior to any excavation or attempted repair. Consideration should be given to the risk of causing further problems (such as lamellar tearing) with the additional thermal strain cycles such excavation and repair would entail.

i. Reflectors in the root pass of butt welds and at the fusion line of the weld shall be evaluated with various probe angles, making an effort of obtain a beam path perpendicular to the fusion line.

j. Level A is admittedly arbitrary, and for many applications, unnecessarily restrictive. However, it may be justified in situations where a large number of false alarms (unnecessary repairs) can be tolerated in order to reduce the number of undetected flaws to an absolute minimum, that is, as a hedge against poorly oriented flaws which might escape detection.

k. In the root area of welds made from one side in tubular T, K, and Y connections, prominent corner reflectors are present which are difficult to evaluate even in acceptable welds. Level A examinations are beyond the current state of the art and not recommended for these areas. Where the service requirements demand this level of quality, consideration should be given to node prefabrication so that the root many be back-welded from the inside. Where Level A examination of root areas in single-sided welds is unavoidable, a 70-degree probe should be used; the reference level calibration reflector should preferably be a 1/16-inch (1.6-millimeter) deep surface notch; and indicated discontinuities should be evaluated in accordance with Figure 44. It should be noted that most of the discontinuities rejected in the roof area may be too small to be confirmed using VT or MT during weld excavation, and gouging out the weld to fix a minor root flaw often results in excessive damage with the repair weld being made under much less favorable conditions than the original defect.

7.10.2 Level C Acceptance Criteria

The following applies concerning Level C acceptance criteria:

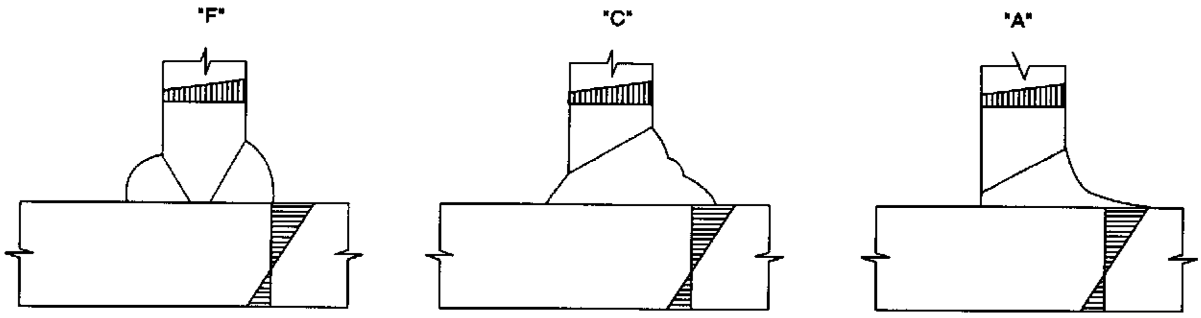


Figure 41—Weld Profile Classifications

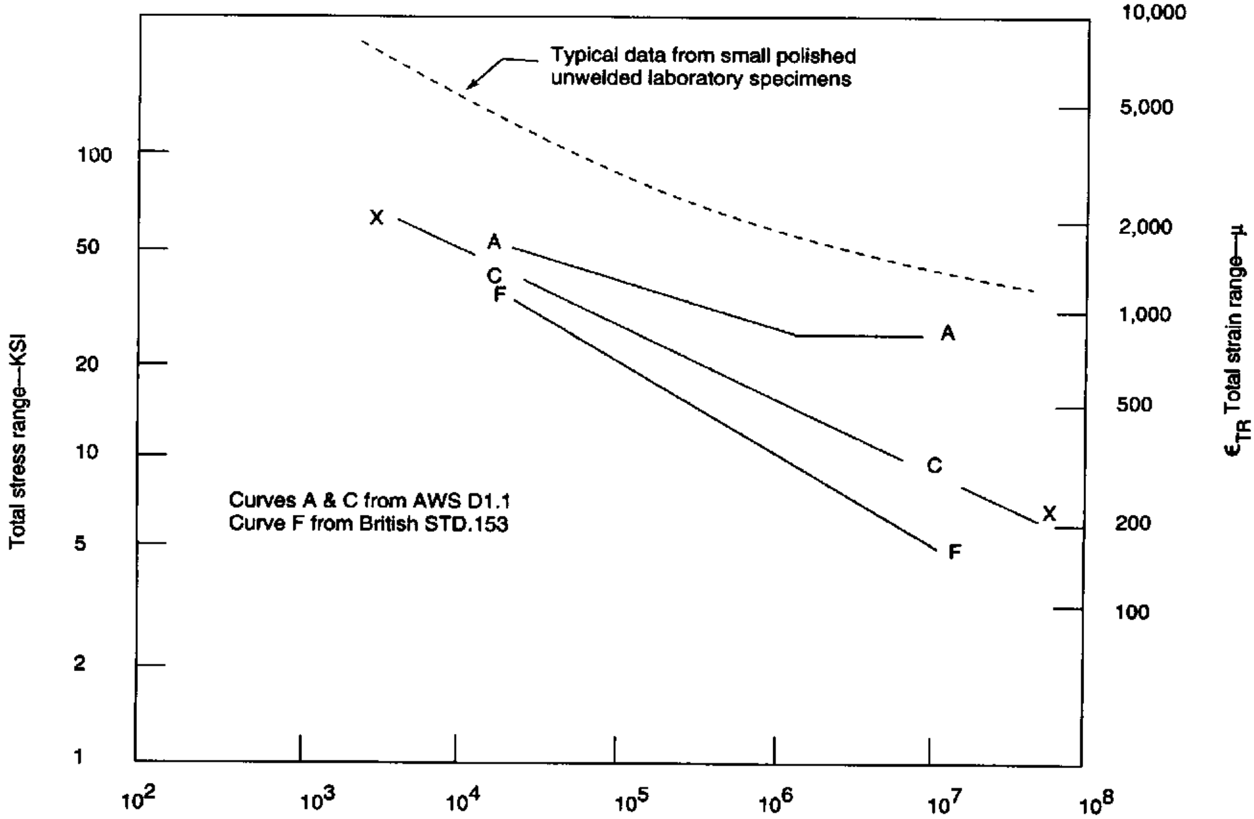
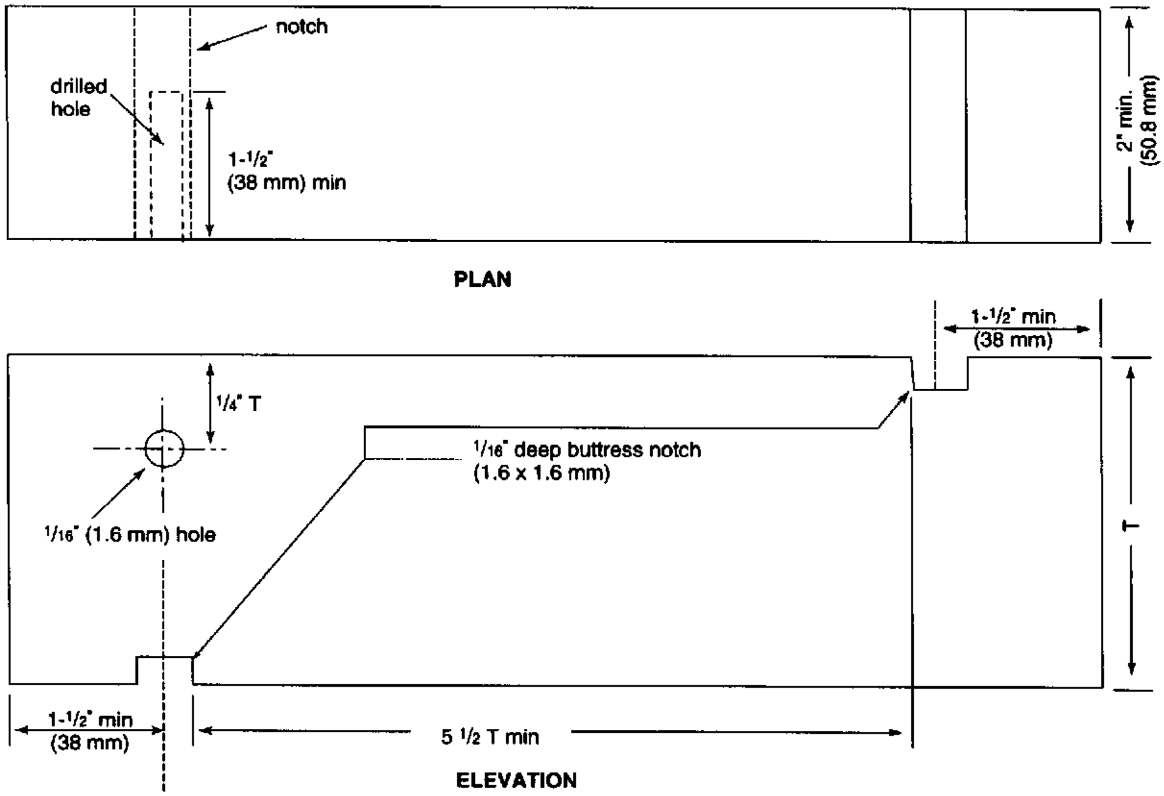


Figure 42—Design Curves for Different Weld Profiles Curve X From API RP 2A-WSD

a. Level C represents experience based on fitness-for purpose criteria which are consistent with as-welded surface profiles (fatigue curve X) in Figure 42 where structural redundancy and a fail-safe design approach is used (as in typical template type offshore platforms) and a reasonable level of notch toughness is provided for all parts of the welded joint.

b. These criteria are specifically tailored for examination of welds made from the outside only in tubular T, K, and Y connections and for practical examination situations in which rejectable defects are subject to visual confirmation during the weld removal and repair process.

c. Discontinuities are evaluated using a combination of beam boundary techniques and amplitude calibration utilizing the transfer and distance amplitude corrections addressed in this recommended practice. The reference level calibration for root reflectors are the 1/16-inch (1.6-millime-



The ultrasonic specialist should determine the value of "T" based on the material and equipment that will be used.

Figure 43—Reference for Level "A" Examination Block

ter) notches shown in the reference standard (block) for Level C examination (Figure 46). The reference level for internal reflectors is the side of the 1/16-inch (1.6-millimeter) hole. Evaluation of a discontinuity is to be based on the ultrasonic operator's best determination of actual flaw dimensions, bearing in mind that interior planar flaws which are poorly oriented with respect to the ultrasonic beam may return a smaller echo than a surface (root) notch of the same size. Flaw size is to be given in terms of width and length as illustrated in Figure 47. In addition, the reflector shall be classified as spherical, cylindrical, or planar and its position within the weld cross section be accurately determined. Identification as to type (such as, crack versus incomplete fusion) is not required.

d. All reflectors 6 decibels smaller than the reference level (that is, 50 percent DAC) may be disregarded (DRL = disregard level). Reflectors above the DRL shall be further evaluated as described in the following sections. The operator may elect to decrease the DRL based on the criticality of a particular component.

e. Isolated, random, spherical reflectors are acceptable, regardless of signal amplitude.

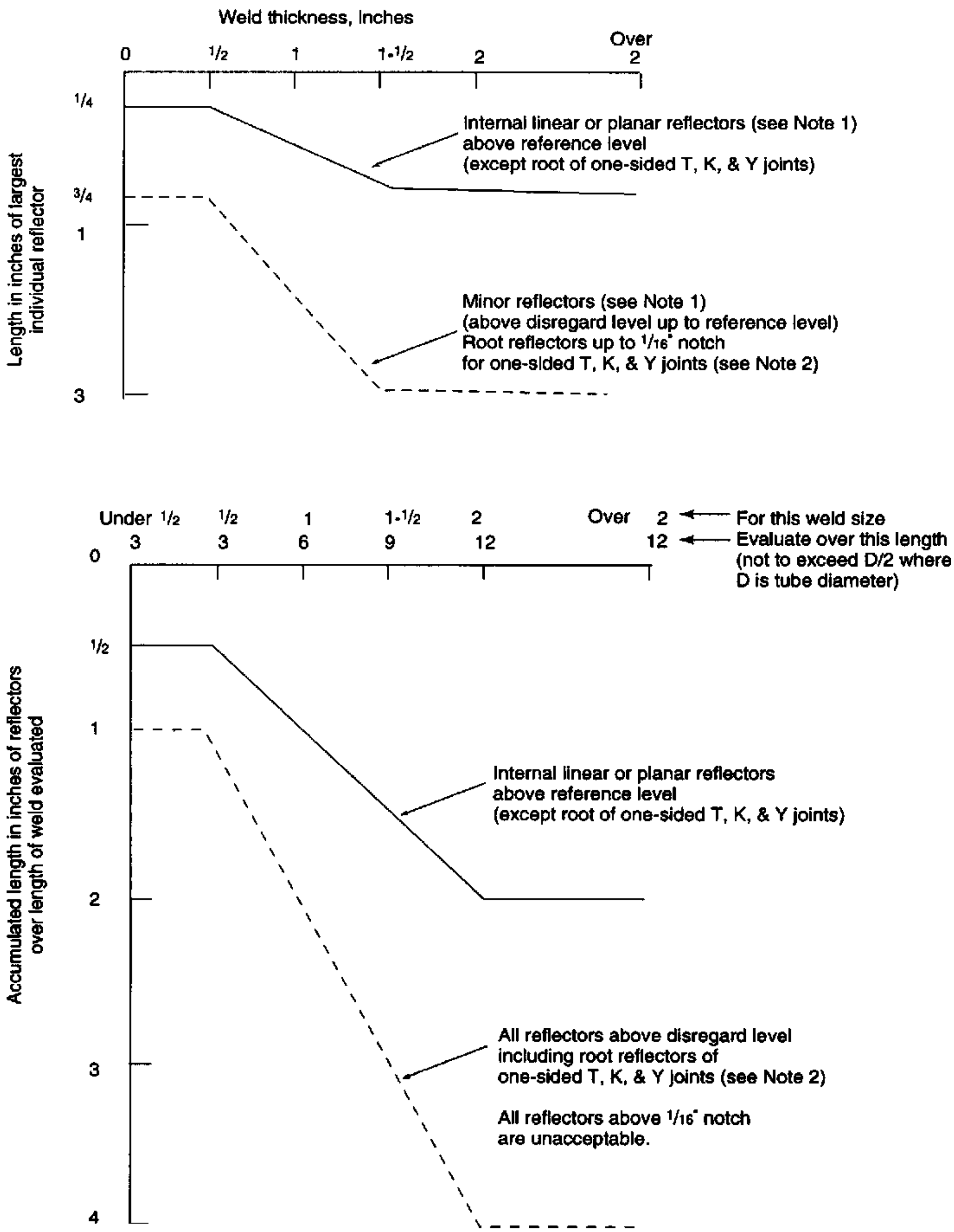
f. Clustered multiple reflectors with indications above the 50 percent DAC curve and two times the branch thickness in length should be evaluated in terms of their encompassing width and length using the limits of Figures 45 and 48.

g. Cylindrical or planar reflectors whose dimensions exceed the limits of Figures 45 and 48 (depending on location) are rejectable.

h. Internal reflectors near the fusion line of a weld shall be evaluated with various probe angles while making an effort to obtain a beam path perpendicular to the fusion line.

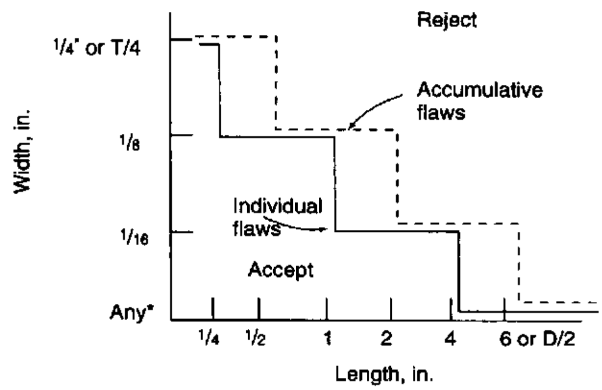
i. Reflectors within the base metal of the main member (joint can) at welds shall be evaluated as described in the following. In addition, any such reflector that exceeds the disregard level shall be reported to the operator:

1. Individual reflectors exceeding the limits of Figure 45 are rejectable.
2. Accumulated reflectors exceeding 8 percent of the area under the weld in any 6-inch (150-millimeter) or D/2 length (whichever is less) are rejectable.
3. Rejectable base metal reflectors shall be reviewed by the operator prior to any excavation or attempted repair. Consideration should be given to the risk of causing fur-



Notes:
1 .Adjacent reflectors separated by less than their average length shall be treated as continuous.
2. Discontinuities in the root bead of Details C and D Figure 12 are to be disregarded.

Figure 44—Level A Acceptance Weld Quality



Notes: Near-surface reflectors: Discontinuities that are within W or T/6 of the outside surface shall be sized as if extending to the surface of the weld. Near-surface reflectors in TKY welds should also be evaluated by other means (for example, grinding).

Figure 45—Internal Reflectors and All Other Welds

ther problems (such as lamellar tearing) with the additional thermal strain cycles such excavation and repair would entail.

j. Note that for welds made from one side only in tubular T, K, and Y connections, greatly relaxed criteria are applied to the root area. Fatigue tests on tubular joints with gross root defects have shown that these do not control failure as long as there is sufficient weld areas to keep the overall stresses from being significantly affected. Not only are defects here less serious, but attempted repairs often create a less desirable condition.

k. Tighter acceptance criteria for all other weld areas still permit somewhat larger discontinuities than traditional radiography-based codes—yet they are consistent with the proposed applications and do not lead to any significant degradation in performance for class C welds. With appropriate overmatching of weld tensile strength compared to base metal yield, static weld failure will not occur due to the minor loss of area permitted.

i. A reasonable level of fracture toughness is provided by selecting base metal and qualifying welding procedures to provide as-fabricated notch toughness in weld, parent material, and heat-affected zones meeting the requirements of API Recommended Practices 2A-WSD or 2A-LRFD.

7.10.3 Level F Acceptance Criteria

The following applies concerning Level F acceptance criteria:

a. Level F criteria permits rotational consideration of various levels of flaw-size criteria, as related to the level of fracture toughness, loading, and other elements of fracture control. Flaw sizes larger than Level C may be justified by such analysis. The resulting criteria may be used to identify those discontinuities which are detrimental to the structure: for example, criteria for underwater ultrasonic examination in fixed offshore structures for which repair of minor flaws would be an unwise allocation of resources with dubious results.

b. Discontinuities are evaluated using beam boundary techniques and careful plotting of the sound path to estimate actual defect dimensions (width and length as defined in Figure 47). Accept/reject criteria should be based on equivalent fracture mechanics crack size a as defined by appropriate analysis.

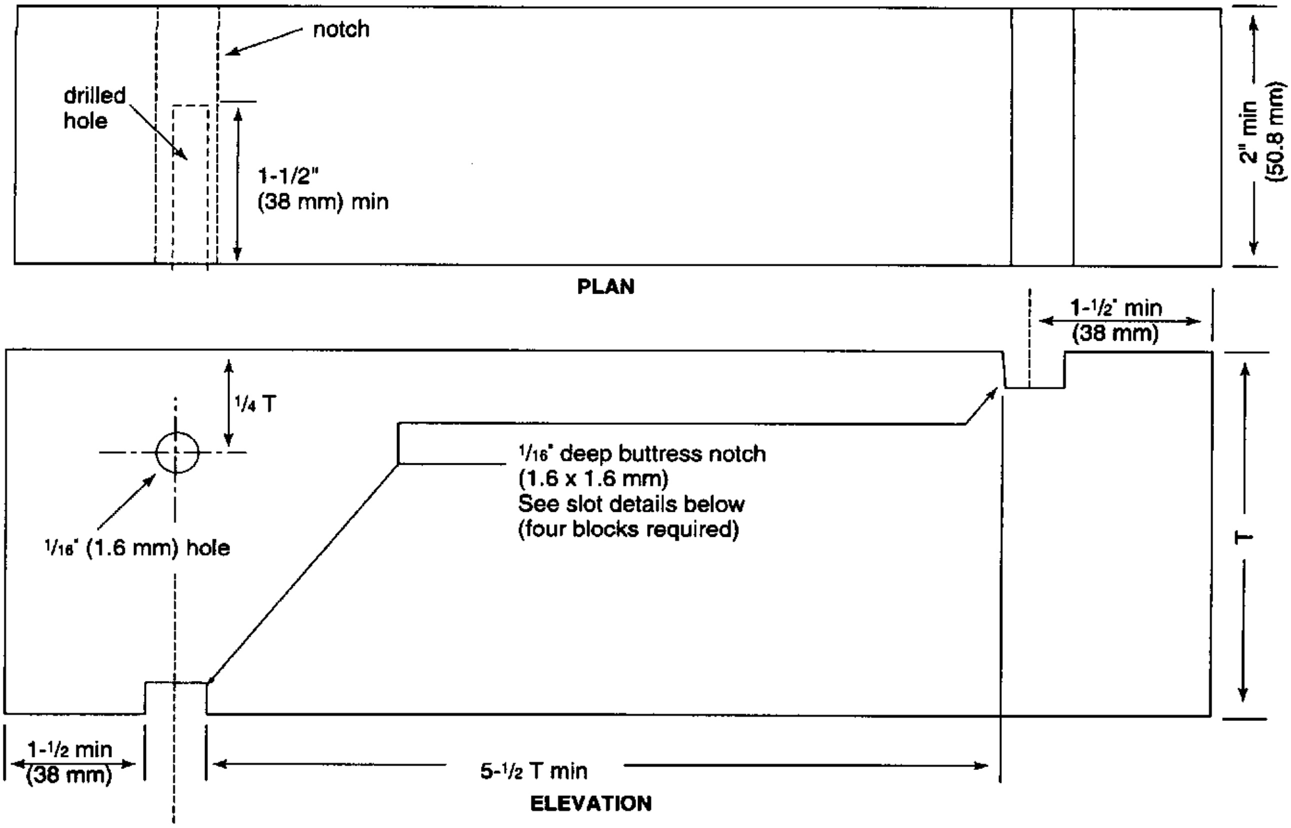
c. Acceptance or rejection should be on the basis of a comprehensive failure mode analysis as outlined here:

1. The static strength based on remaining net section should be adequate.
2. Brittle fracture should be precluded by demonstrating that the equivalent crack size a is less than the critical crack based on appropriate local stress (including residual stress), material thickness, loading rate, and temperature for the application.
3. The fatigue life required to grow a crack from initial size a to terminal size defined by the preceding static strength or brittle fracture criteria should be adequate.
4. Due allowance should be made for uncertainty in the various fracture mechanics correlations used and for errors in the ultrasonic crack sizing.

7.10.4 Reference Blocks

The reference reflector for establishing the scanning sensitivity must be compatible with the flaw acceptance criteria and provide sufficient sensitivity to ensure detection of the smallest discontinuity of interest.

For ultrasonic examination at Level A acceptance criteria, the side of a 1/16-inch (1.6-millimeter) drilled hole provides an excellent reference for use with all transducers. The thickness and length of the block containing the drilled hole should permit evaluation of reference sensitivity at the longest metal path distance anticipated in the actual examination (see Figure 43). In addition to the side-drilled holes employed for evaluation of all discontinuities in the body of the weld, two 1/16-inch (1.6-millimeter) deep notches are suggested as reference standards to be used in evaluating root reflector in butt or T, K, and Y connections welded from one side only.



Note: Simulated references for rejectable flaws established by the Operator's ultrasonic specialist should be added to these blocks for the calibration of internal reflectors, that is, 3/4" in. side-drilled hole. A minimum of four blocks should be prepared, each with a minimum of one notch described below. The ultrasonic specialist should determine the value of T based on the material and equipment that will be used.

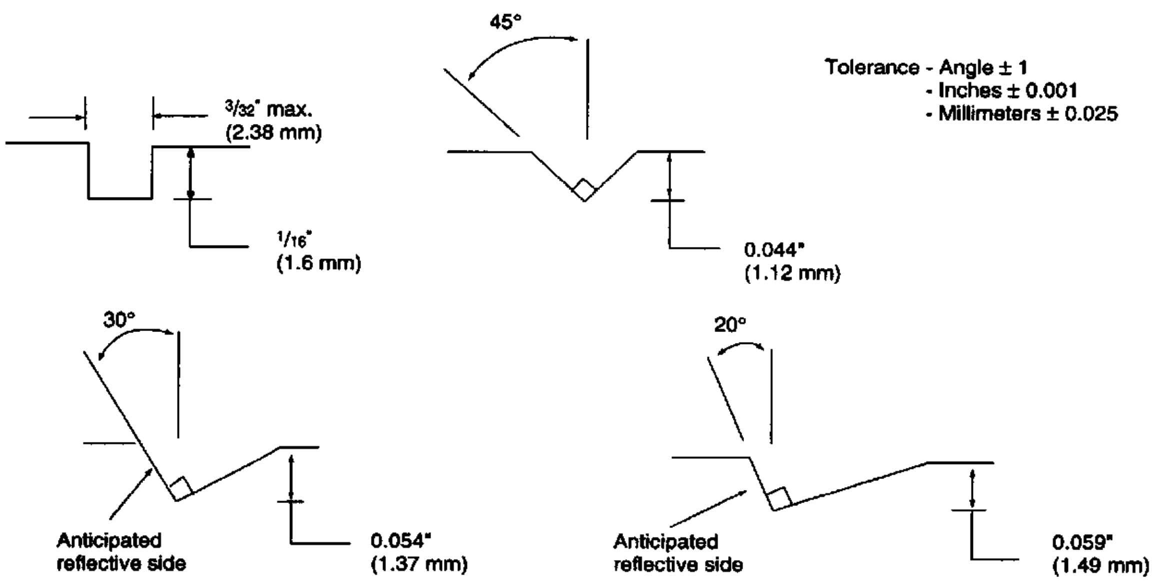


Figure 46—Reference for Level C Examination Block

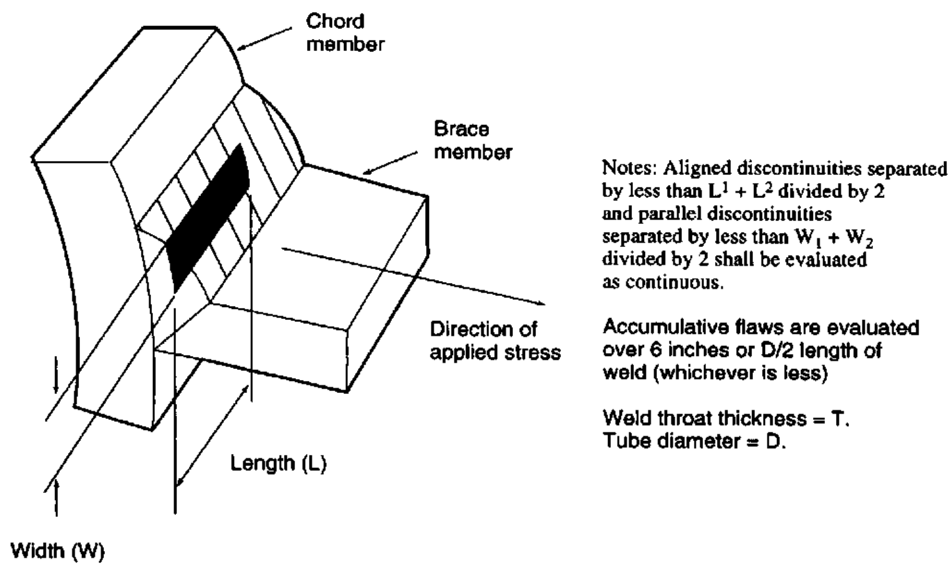


Figure 47—Definitions

The reference block for a Level C examination should contain planar reflectors compatible with the smallest rejectable flaw. One reference block containing a square (buttress) notch and one each with V-notches for 45–degree, 60–degree, and 70–degree orientations should be available for establishing scanning sensitivity for root reflectors. In addition to notches for root reflectors, the side of a 1⁄16-inch (1.6-millimeter) drilled hole provides an excellent reference for internal reflectors (see Figure 46).

The response from known size implant reflectors in the operator's test coupons should be compared with the reflections from the reference blocks to assure that the sensitivity will result in detection of the smallest flaw of interest.

7.11 REPORTING

7.11.1 A set of structural drawings should be marked with an appropriate weld identification system detailing the location of each weld to be examined, and this identification should be recorded on the report. These drawings and reports become the record of examination.

7.11.2 A report of each weld examination performed shall be prepared. The details of the examination should be documented in sufficient detail to permit repetition of the examination at a later date. Details of acceptable discontinuities should be documented to acknowledge their presence (for example, incorporated tack welds, porosity material imperfections, and so on.) Full-scale sketches and drawings are desired to augment descriptions of the weld or material and locations of all rejectable discontinuities. The form shown in Appendix D provides the required details of documentation. Sketches of typical weld configurations as shown in Figures 41–48 provide clarity of the written description. Identify all flaws on sketches by the appropriate weld number and clock position.

7.12 VERIFICATION

When visual confirmation by excavation of ultrasonically examined welds is desired, the following procedures are recommended:

a. After several discontinuities of reject classification have been indicated, a confirmation team is formed at the convenience of all involved. The team should consist of a skilled craftsman furnished by the fabricator for excavation of the indicated area, a representative of the fabricator's quality-control group, the ultrasonic personnel and the operator's inspector.
b. Metal obscuring visual examination of the discontinuity indication should be removed by air-arc gouging, grinding, or other mutually agreed-upon method. When approaching the indicated location of the discontinuity, the amount of metal removed between successive visual examinations should be restricted to 1⁄16 inch (1.6 millimeters) and all present should be afforded an opportunity to observe the result before proceeding with additional excavation.
c. Flaws which are observed visually and exceed the permitted limits of the contract specification shall be deemed as verified.
d. Repair of welds shall conform to methods detailed in the contract specification and qualified by the fabricator.

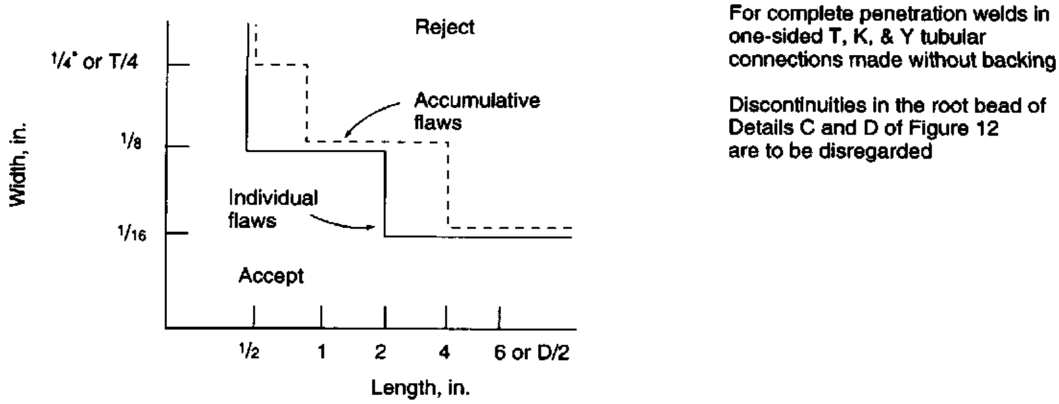


Figure 48—T, K, and Y Root Defects

8 Technical Recommendations for Magnetic Particle Testing

8.1 APPLICABILITY OF MAGNETIC PARTICLE EXAMINATION TO OFFSHORE STRUCTURES

Surface-breaking toe-of-the-weld imperfections are detrimental to in-service fatigue performance. Wet and dry magnetic particle (MT) examination is well suited to the detection of such surface-breaking imperfections in these areas, and can also sometimes be used as a proof test for visual and ultrasonic indications found in ferromagnetic structures.

8.2 ADVANTAGES AND LIMITATIONS

The MT technique described detects short, shallow surface flaws such as cracks and incomplete fusion. The sensitivity of the technique, when correctly performed by qualified personnel, is such that ¼ inch (6 millimeters) long by 1/32-inch (0.8-millimeter) nonvisual [typically less than 1 1/1000-inch (2-microns)] wide surface-breaking imperfections can be detected.

The advantages of the technique are that the surface magnetic field level in the inspected area may be checked very simply with a pie gauge or other magnetic field indicator while the field is continuous, and the technique may be performed through painted surfaces where proven performance can be demonstrated. The MT technique may also be conducted in the residual magnetic induction following magnetization.

In addition to inspecting the final weld, MT can be used to inspect root and intermediate passes on large cross-sectional welds. By using dry powders, the technique may be applied while the weld is still hot. However, there is a decrease in ferromagnetic behavior as the temperature rises, which should be taken into account.

Limitations of the technique are that imperfections must be initially clean and dry, and the area must be magnetized in a direction that is substantially perpendicular to the opening of the imperfection. This may generally involve applying magnetization in at least two perpendicular directions. The inspected material must be ferromagnetic.

8.3 PROCEDURE QUALIFICATION AND APPROVAL

The following applies concerning procedure qualification and approval of magnetic particle testing:

a. Written MT examination procedures should be prepared by the NDE specialist, approved by the owner, and continue in force until cause is shown to question their validity.
b. The following list of essential variables should be covered in the written procedure:
1. Type of weld to be examined.
2. Type of magnetizing equipment, including type of current employed, and the use of residual induction (if employed).
3. Surface preparation.
4. Examination sequence.
5. Magnetization plan.
6. Magnetic field direction for continuous method.
7. Magnetic field strength at inspection location during continuous magnetization.
8. Magnetic particle type—wet or dry—and color contrast with inspected area.
9. Interpretation of indications.
10. Acceptance criteria.
11. Reporting form(s) and procedure.

c. An evaluation of the system performance and sensitivity should be demonstrated prior to the beginning of any testing work. This may be included within the written procedure.
d. Variations from the accepted procedure should be taken as cause for re-qualification of the procedure.

8.4 Equipment

8.4.1 Technique

For this practice, the continuous method which employs alternating current (AC) electromagnetic yoke (double leg, or single leg configuration) with either dry white-light-visible or wet magnetic particles should be used. The inspected surface shall be cleaned where necessary and covered with a light contrast coating (typically white-contrast paint less than 0.002 inches thick). The method requires that the examination take place while the magnetizing current is *on*, including application of particles, removal of excess particles, and indication interpretation. Rectified AC (in other words, DC) and residual induction methods may also be employed as a check on the continuous AC method whereby further confidence in the results is gained.

8.4.2 Yokes

8.4.2.1 Yoke Selection

Yokes shall be of the AC or DC (rectified AC) articulating-leg type to allow for the inspection of various geometries. A single-leg yoke can be used in areas of tight access. Fixed-leg yokes should not be employed. AC yokes should have a lifting power of at least 10 pounds (2.2 kilograms) when the legs are spaced at the inspection distance. DC yokes should have a lifting power of 40 pounds (8.8 kilograms) when the legs are spaced at the inspection distance.

8.4.2.2 Magnetizing Field Terminology for Yoke Inspection

Since lines of flux run generally longitudinally between the poles of a yoke (see Figure 49), the term *longitudinal magnetization* will be employed in this document to describe this situation. Flux lines flow radially in the part from a single leg yoke (Figure 50); and the term *radial magnetization* is used in this document to describe this situation.

8.4.2.3 Magnetizing Field Direction During Yoke Inspection

Field direction is important because the strongest magnetic flux leakage fields from imperfections are produced when the lines of flux cross the discontinuity perpendicularly. Indications will not generally be produced when the lines of magnetic flux run parallel to the discontinuity.

8.4.2.4 Verification of Performance and Sensitivity

Yokes should be routinely tested as described in 8.6 to ensure that the required magnetization performance and sensitivity levels are met during inspection.

8.4.3 Magnetizing Current

From 50 hertz to 60 hertz AC electro-magnetization is optimal for detection of surface-breaking discontinuities and will be used as the primary method in this recommended practice. AC causes a "skin effect" which restricts the magnetizing field to the part surface, and creates good particle mobility. System sensitivity is checked with a suitably located pie gauge.

In wet condition, a suitable ground fault interrupter shall be used with AC in order to ensure proper safety for the technician against electrical shock.

On many yokes, the current may be changed from AC to rectified AC (that is, DC). This is useful for deeper penetration of the magnetizing field into the part and for establishing residual induction if it is desired that MT be performed under these conditions.

8.4.4 Magnetic Particle Material and Application

The particles shall be non-toxic, finely divided high-permeability ferromagnetic material with low retentivity and a suitable size range. Dry particles shall have 75 percent (wt) finer than a 120 ASTM sieve mesh, a minimum of 15 percent (wt) dry particles being finer than 325 ASTM sieve size. Their color shall be selected to provide high contrast to the background on which they are to be applied. Particles shall be free from rust, fillers, or other material that could interfere with their use.

Magnetic particle materials shall be used only once.

Particle application and removal equipment (that is, powder bulbs, aerosol sprays) shall be such that fine indications are not removed by excessive force. A powder bulb with many 1/32-inch holes is optimal.

8.4.5 Lighting

Lighting requirements are as follows:

a. Adequate "white light" shall be provided for observation of particle indications. White light may include natural daylight, or tungsten, or fluorescent lights. Since inadequate lighting can degrade visual acuity, the inspector should check the contrast between the particle indications and the background when working in artificial light.
b. A minimum of 100 foot-candles (1000 lux) shall be present at the inspection location. This should be measured with a calibrated light meter.
c. Since flashlights generally do not provide sufficient illumination, yoke-mountable lamps are recommended where necessary.
d. Adequate white light (> 100 foot-candles) is also required for the performance of visual inspection at magnetic particle indication sites.
e. For verification of lighting level, lighting requirements should be routinely tested (see 8.6) to ensure that minimum lighting conditions are met.

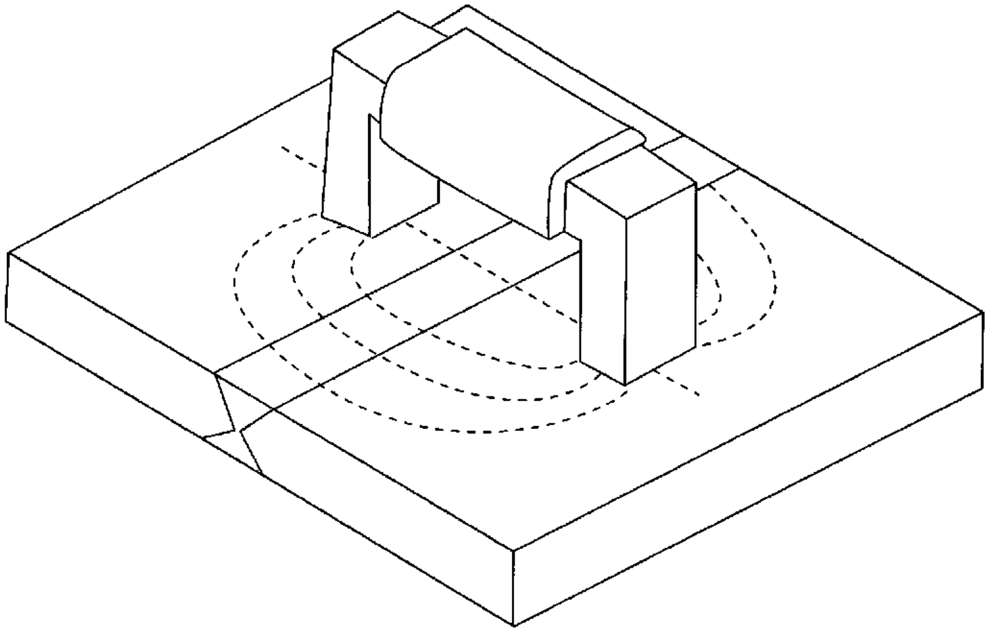


Figure 49—Longitudinal Field Produced by Electromagnetic Yoke Setup

8.5 EXAMINATION TECHNIQUE

8.5.1 Examination Plan and Acceptance Criteria

A written examination plan should be developed according to the geometry of the pieces to be inspected, yoke application, light levels, accessibility, safety, and other factors which could affect system performance. Examinations should always be conducted with sufficient overlap to ensure 100 percent coverage. However, if the geometry of the piece does not permit the inspector to perform 100 percent evaluation of the piece, this information must be made available on the report to the owner.

Unless otherwise specified, the owner shall specify the areas and percentages of the part to be examined by MT. The owner may ask the contractor to submit a practice of identifying (naming) specific joints to be inspected. On certain welds, it may be desirable to require inspection starting and finishing points to be marked. The owner should specify whether the weld to be examined shall be temporarily or permanently marked with a marking technique that is approved by the owner. The owner should also specify any acceptance criteria for the test in the examination plan. (Typically, any linear discontinuity is rejectable. However, the owner may also define reportable limits of other weld conditions.)

The location and specific area of coverage for the MT inspector should be verified and referenced to the examination plan or drawings, and should be referenced on the MT general report.

The examination plan should also include the technique. Typically, two options exist for the detection of fabrication discontinuities, as follows:

a. MT for both longitudinal and transverse discontinuities (see Figures 53 and 54).
b. MT in one discontinuity direction only.

During fabrication, the MT inspection should check for discontinuities at all angles, with the part being magnetized in at least two perpendicular directions.

For in-service inspection, the major class of discontinuities that occur on fixed offshore structures are longitudinal toe cracks, and in order to maximize inspection efficiency, the owner may specify that MT be performed for such discontinuities and directions.

8.5.2 Identification and Marking of Welds

The owner may specify, or ask the testing agency to submit, a practice for identifying (naming) specific joints inspected.

On certain welds it may be desirable to mark inspection starting points, or areas of relevant indications. The owner should specify whether the weld to be examined should be temporarily or permanently marked. Marking techniques should be approved by the owner.

If permanently marked, the marking should be sufficient to retain its identify until after final evaluation and subsequent evaluations. It is recommended that materials tested and found to have relevant discontinuities be permanently marked to facilitate relocation and re for repair purposes. A low stress "arrow" stamp is recommended for this purpose.

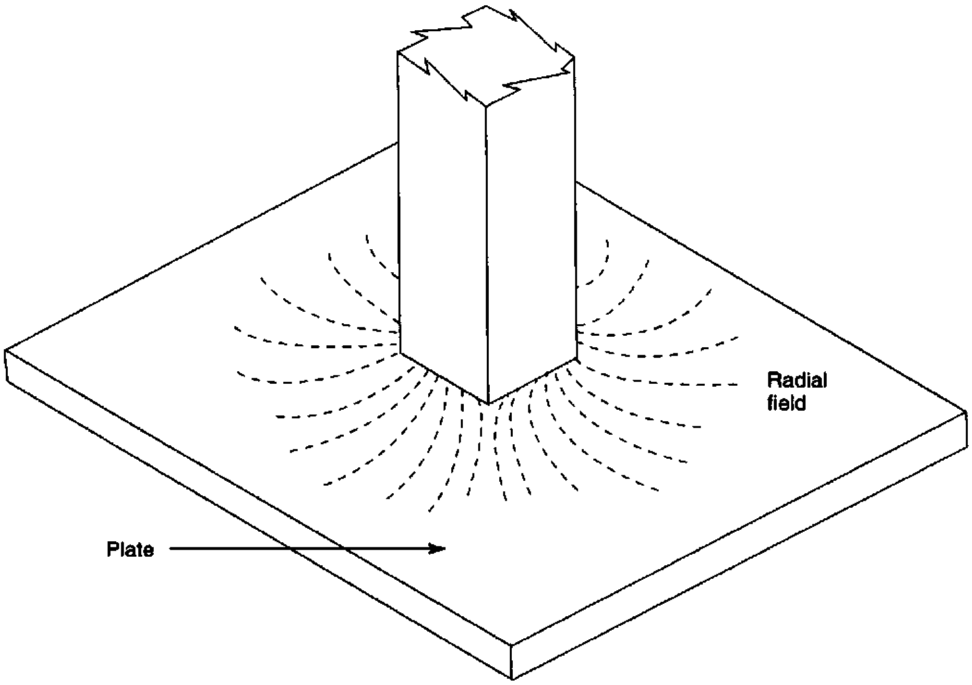


Figure 50—Radial Field Produced by "Single-Leg" Electromagnetic Setup

8.5.3 Surface Preparation

8.5.3.1 Surface Condition

Proper surface condition is essential to MT. All welds should be inspected visually for detection of gross imperfections and demarcation of the area to be cleaned before the application of any paint or coating.

Cleaning to bare metal prior to MT can be accomplished by grinding, sand blasting, water blasting, wire brushing, needle scalers, hand scraping, or a combination of these. Cleaning removes weld splatter, rust, and any existing paint, but should not be sufficiently powerful to close potential indications.

Welds to be inspected in the "as-welded" condition shall be dry and free from contaminant materials such as dirt, grease, and weld splatter. A light coating of contrast paint shall be applied to assist in defection of smaller imperfections.

8.5.3.2 Painted Material

Welds which have been painted for other reasons shall have the coating removed unless adequate sensitivity to MT can be demonstrated. Typically, a paint thickness in excess of 0.006 inch may reduce the sensitivity of MT by the AC yoke method to an unacceptable level. It is often necessary to remove the coating only in the area of interest, typically the weld and heat affected zone.

Where uncertainty of the coating thickness exists, it should be checked with a calibrated dry file thickness gauge. Calibration should be performed to be accurate within the range to be measured.

8.5.4 Yoke Placement and Leg Orientation

See Figures 49, 50, 53, 54, 55, 56, and 57 for yoke placement and leg orientations. To be inspected in the longitudinal direction, the yoke should be astride and perpendicular to the weld. For inspecting the weld to be inspected in the transverse direction, the yoke should be oriented so that it is basically parallel to the weld.

8.5.4.1 Examination for Longitudinal Discontinuities with a Yoke

Figures 51 and 55 show preferred methods of placement of the yoke when inspecting a T-connection. A similar yoke configuration should be used when inspecting a Y-connection.

The effective inspection area is the weld between the yoke legs, and a lateral area of approximately 1.5 inches (38 millimeters) on each side of the centerline of the yoke legs. The total effective area of linear weld coverage for one position of the yoke is approximately 3 inches (76 millimeters). This effective area is dependent upon the leg spacing and part geometry which determines the tangential magnetic field strength at the part surface. This can be quantified by the use of an electronic Hall-effect gauss meter (tesla meter). (See 8.6.)

Sufficient overlap should be used to ensure 100 percent coverage when moving along the weld length. Yoke move-

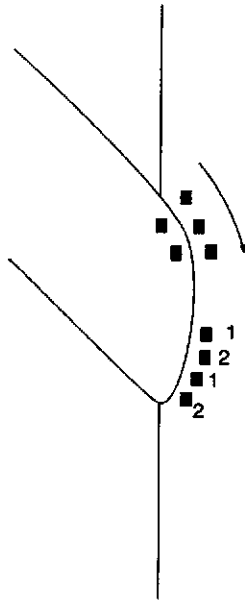


Figure 51—Magnetization Plan Setups

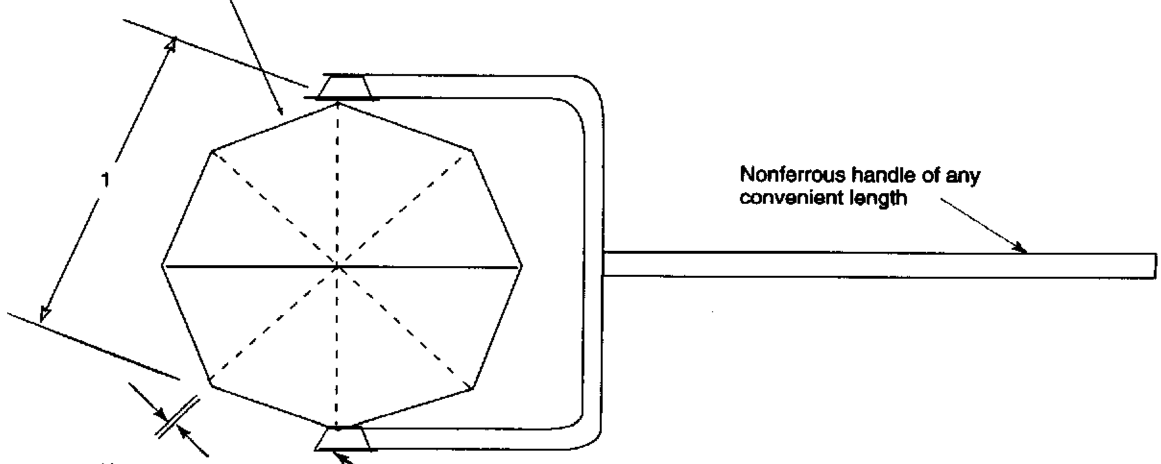


Figure 52—Illustration of API-Recommended Magnetic Field Indicator

ment in 2-inch (50 millimeter) intervals should ensure adequate overlap.

The yoke legs should be positioned such that they are approximately 1 inch to ½-in. (25–12 millimeters) from the toe of the weld. This places a strong magnetic field strength at the toe of the weld, the area of highest predicted discontinuity occurrence. In testing the weld, the yoke may be dragged slowly over the inspection area. However, when inspecting Y-connections, adjustments to the yoke legs will be necessary to make sure that the legs have good contact with the surrounding base metal.

8.5.4.2 Examination for Longitudinal Discontinuities With a Single-Leg Yoke

When inspecting in the longitudinal direction, one may not be able to gain access to all locations, for example, the

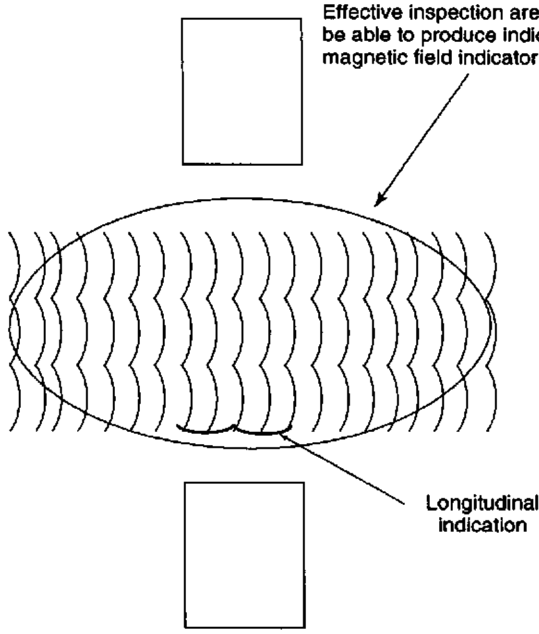


Figure 53—Electromagnetic Yoke Setup for Detection of Longitudinal Discontinuities

heel and toe zones of a tubular Y-connection. In these locations a single-leg method may be used. This places a radial field in the part (see Figure 50).

This may be accomplished by moving one leg out of the way to gain access. Acceptable results can be obtained when the yoke leg is laid flat against the area being inspected (see Figures 56 and 57).

In this configuration, the effective inspection area should be surveyed with a Hall-effect gauss meter (tesla meter). The single leg should be placed ½ inch (12 millimeters) from the weld. The total effective inspection area may be as little as one square inch in front of the leg. For this reason, it may be necessary to place the single leg on the base metal on each side of the toe of the weld in order to assure that an adequate magnetization has occurred.

Sufficient overlap should be used to assure 100 percent coverage when moving along the weld length; movement in ¼-inch intervals should assure adequate inspection overlap.

8.5.4.3 Inspection for Transverse Discontinuities With a Yoke

Transverse indications are best detected when the weld is scanned with the yoke legs parallel to the weld and approximately ½ in. (12 millimeters) from the toe. If the yoke has to be placed on top of the weld to gain access, the technician should ensure the best contact possible of the yoke legs to the weld (see Figure 54).

The effective area will be the weld between the yoke legs. A 4-inch (100 millimeter) leg spacing is recommended. Sufficient overlap can be achieved by moving the yoke to a position which overlaps the last position by at least 1 inch (25 millimeter). If the weld is extremely wide [greater than 2 inches (50 millimeters)], it may be necessary to inspect by placement of the yoke on both sides of the weld.

8.5.5 Application of Particles

8.5.5.1 Dry Particles

Dry particles shall be applied in such a manner that a light, uniform, dust-like coating of particles settles on the part while it is being magnetized. The MT personnel should observe for particle indications being formed as the powder is being applied, and while the excess is being removed.

Care must be taken in removing excess particles, so that fine, or weakly held indications are not removed. However, sufficient velocity must be directed at the area of inspection to remove the excess particles that are not primarily held by magnetic flux leakage from discontinuities, but rather by mechanical entrapment in areas such as weld undercut and under-bid.

If DC excitation is used, indications may remain in residual induction.

8.5.5.2 Wet Particles

When using the wet method, excess particles are usually removed by gravitational drainage. Therefore when working on a flat surface, care must be taken to produce a background that does not produce excessive particle background, which can cause false indications.

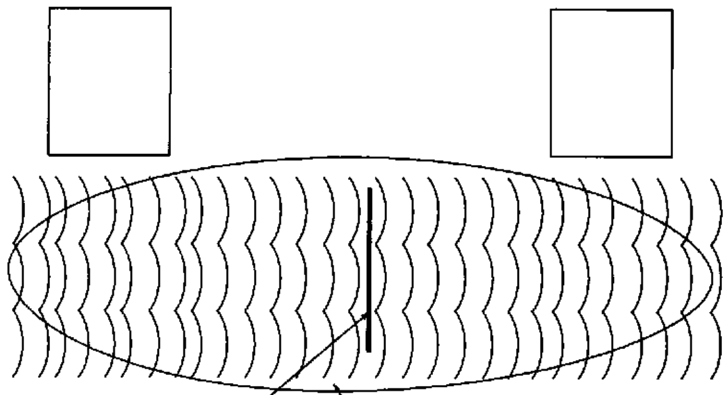


Figure 54—Electromagnetic Yoke Setup for Detection of Transverse Discontinuities

Particle removal velocity should be determined by use of a magnetic field indicator (pie gauge), or by the use of a test specimen.

If DC excitation is used, indications may remain in residual induction.

8.6 EQUIPMENT PERFORMANCE CHECKS (STANDARDIZATION) AND EVALUATION OF SYSTEM SENSITIVITY

The performance and sensitivity of a magnetic particle inspection (that is, the combination of magnetizing and illuminating equipment, magnetic particle material, the sequence of operations, and the like) should be monitored at regular intervals to assure the required performance level. The tests to be discussed in this section should be performed at the following times:

a. Prior to each examination.
b. At the end of each examination.
c. Any time that the MT personnel and/or owner feel that conditions have changed which might affect the sensitivity of the MT technique.

The following MT performance/sensitivity parameters should be checked prior to performing any examination and should be documented by a written procedure. This is sometimes referred to as *standardization:*

a. Yoke magnetizing strength.
b. Yoke set-up.
c. Field Direction.
d. Magnetic Particle performance.
e. Excess particle removal force.
f. Lighting at inspection surface.

8.6.1 Yoke Magnetizing Strength

To check yoke magnetizing strength, proceed as follows:

a. Check that the AC yoke will lift a 10-pound (2.2-kilogram) steel bar with the legs at the inspection spacing.
b. Check that the DC yoke will lift a 40-pound (8.8-kilogram) steel bar with the legs at the inspection spacing.
c. Note that 2-leg or 1-leg yoke should produce clearly defined indications on a magnetic field indicator (pie gauge—see Figure 52 in the area of inspection). The indication must remain after excess particles have been removed.

A two-leg or one-leg yoke should produce a minimum of 30 Oersted (24 Amperes/centimeter) in air in the area of inspection (see Figures 53 and 54). The field strength that is tangential to the inspected surface may be measured with a suitably calibrated Hall-effect gauss (tesla) meter.

Field distribution plots of iso-magnetic lines can be made for various yoke and part configurations in order to verify the inspection area envelope.

8.6.2 Yoke Set Up

A magnetic field indicator should be used to verify each yoke set-up. Clearly defined magnetic particle indications must appear on the indicator prior to inspection.

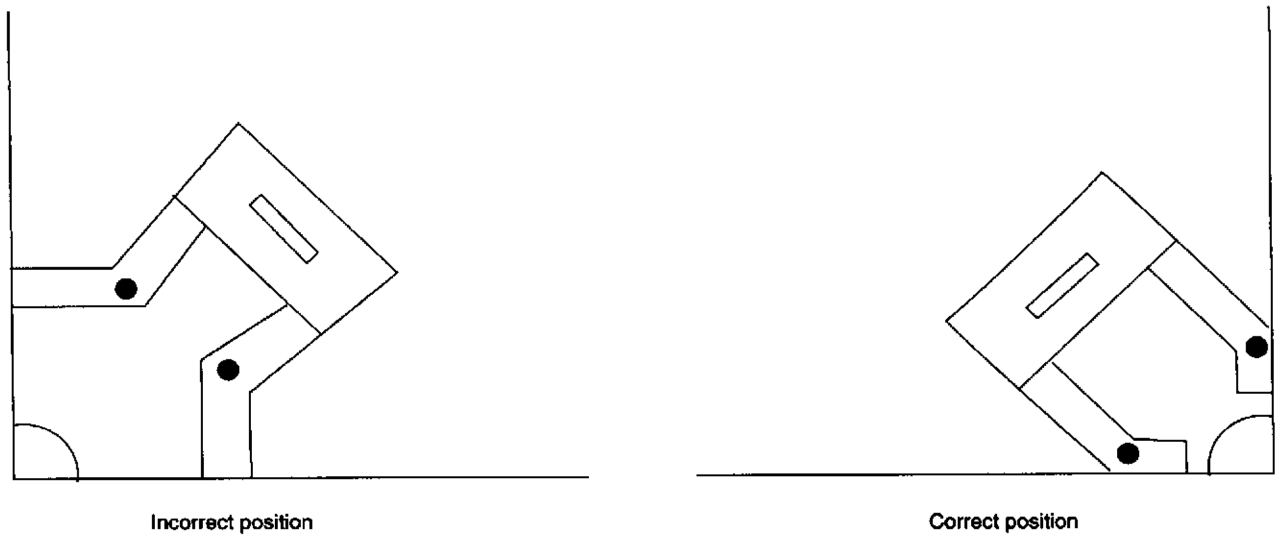


Figure 55—Incorrect and Correct Electromagnetic Yoke Setup for T and Y Joint Connections

8.6.3 Magnetizing Field Direction

A magnetic field indicator should be used to check the correct orientation of the yoke relative to the field it produces and the direction of discontinuities that it can detect. The discontinuities on the field indicator should be placed in the same direction as the discontinuities in the weld required to be detected.

8.6.4 Magnetic Particle Performance

Dry magnetic particles should be checked for compliance to the ASTM mesh condition (see Section 8.4.4) prior to starting an examination.

Wet magnetic particle solution should be checked for compliance to manufacturer's optimal concentration level with a settling test at least once per day.

Clear indications with each type of particle on the field indicator placed midway between the legs of a yoke located in a steel test surface should be observed.

8.6.5 Excess Particle Removal Force

A field indicator should be used to adjust the force required to remove excess particles without removing indications. However, specimens containing field-removed discontinuities or fabricated discontinuities provide optimum means to practice particle removal skills.

8.6.6 Lighting Levels

White light intensity should be verified at the inspection surface using a suitable light meter.

8.6.7 Use of Field Removed Discontinuity Specimens

Representative field-removed specimens with known discontinuities can provide a reliable means to quantify and evaluate the performance and sensitivity of a magnetic particle testing practice. The specimens and flaws should be of the types and severity normally encountered during fabrication. Such test specimens should be considered when evaluating a testing agency's performance and qualifying inspection personnel.

8.6.8 Use of Specimens With Manufactured Discontinuities

Effective discontinuities for evaluating the performance of MT procedures or personnel can be manufactured by contaminating the weld pool of a weld test coupon with copper as the surface bead is being deposited. This can result in a fine network of cracks.

8.7 INTERPRETATION AND EVALUATION OF INDICATIONS

Relevant MT indications result when magnetic flux leakage (MFL) fields formed by discontinuities attracts and holds magnetic particles. Other MT indications caused by particles held by nonmagnetic forces or weak leakage fields from weld geometry or permeability changes are termed *false indications*. MT indications incorrectly evaluated as relevant indications are termed *false positive indications*.

False indications are those which are held primarily by non-magnetic means, for example, mechanical entrapment in the toe of a weld. Typically, however, they will not produce sufficient MFL to produce a relevant indication. This occurs because of the following:

a. The discontinuity geometry produces a low depth-to-width ratio.
b. The flux lines flow beneath the discontinuity and those which do emerge generally have insufficient curvature to hold particles.

If excess particles are not properly removed, the possibility arises for false interpretation.

The term *non-relevant indication* is often used in conventional MT to mean a particle indication which is held in place by magnetic attraction, but does not originate from a structural discontinuity. An example of this is the MT indication formed at the boundary of two steels having significantly different magnetic permeabilities. Magnetic nonrelevant indications can be created by the hardened heat-affected zone of a weld, but can usually be identified by their diffuse nature.

Testing personnel should properly evaluate indications by the following:

a. Reevaluation of the indication by retesting with the yoke field perpendicular to the discontinuity indication if it is not already perpendicular.
b. Re-testing and ensuring that excess particles are removed. If the suspect indication is removed during the retest, the indication is interpreted as not relevant, or as a false indication. Typically relevant indications retain particles after all excess particles have been removed.
c. If the indication has a light particle buildup and weak particle adhesion, and if doubt exists as to whether the indication is relevant or false, the area of the indication should be lightly surface-ground and retested.

Conversely, care must be taken to ensure that relevant indications are not masked by nonrelevant ones.

Overlap and undercut may cause relevant surface indications. Both can cause problems by masking weld toe cracks. They can be visually identified, producing a light MT indication, and can be interpreted and evaluated by light surface grinding.

As commonly practiced, MT does not provide quantitative information regarding imperfection. For the purpose of this practice, an attempt should be made to provide particle buildup information as a function of discontinuity depth. A heavy buildup with strong adhesion of the particles almost always indicates a discontinuity depth greater than 1/32-inch to 1/16-inch (0.7 millimeter–1.5 millimeter). A fine buildup with light adhesion will typically indicate a hallower discontinuity, or one which is in heavy compression. Light surface grinding of indications that have a fine buildup may provide relative information on the width of the discontinuity. Evaluation of whether the indication is in compression or tension should be performed by a qualified engineer.

Indications may be qualitatively classed by depth as being shallow surface (less than 1/32-inch) or greater than shallow surface (greater than 1/32-inch).

Any additional information pertinent to the indication should be detailed under the remarks section of the Magnetic Particle Indication Form (Appendix D).

All final evaluations should be performed by qualified Level II MT personnel who are also responsible for ensuring that all required information is documented on the appropriate report form(s).

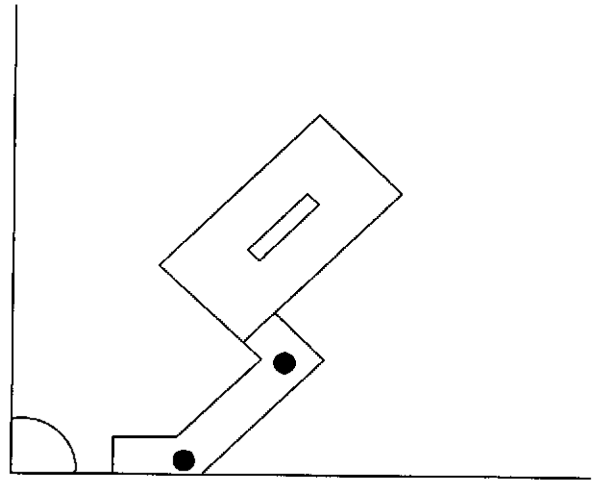


Figure 56—Acceptable Setup for Scanning with "Single-Leg" Electromagnetic Method

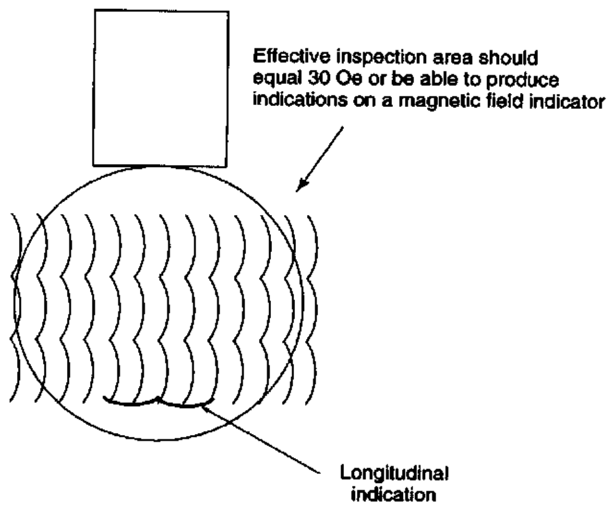


Figure 57—Single-Leg Electromagnetic Setup for Detection of Longitudinal Discontinuities

With proper grinding techniques, shallow surface cracks or incomplete fusion can be ground out, making an effective repair. The following guidelines apply:

a. Owner approval: grinding is a means to further interpret and evaluate MT indications. Extreme caution should be taken to implement and use proper grinding techniques since improper grinding can create stress risers where sound weld may have existed. Grinding should be approved by the fabricator and the owner.

b. Dimensional requirements: A maximum of 1/16-inch (1.5 millimeter) metal removal is permitted unless otherwise specified by the owner. This will ensure that the proper weld size and profile remain and that stress risers are not induced at the grinding site. The grinding should be contoured, radiussed, and blended into the area of the weld and/or surrounding base metal. Grinding should be tapered for 2 inches (50 millimeters) past each end of the indication to optimize metal contouring.
c. Type of grinders: pencil-type grinders with radiussed burrs are recommended. Grinding-wheel tools are acceptable, with small diameter and thickness wheels preferred.
d. Measurement of grind: the depth of the grind should be continuously checked during the grinding process with a calibrated mechanical measuring device.
e. Retest: all indications that are ground should be continuously reinspected with MT with the yoke in the same position as that which was used to detect the discontinuity. It may, however, be necessary to use magnetic particles of a different color in order to have good contrast with the newly ground metal.

8.8 ACCEPTANCE CRITERIA

All relevant indications, as determined by MT (typically cracks or incomplete fusion) are rejectable regardless of length otherwise specified by the owner. All relevant indications must be reported.

8.9 REPORTING

8.9.1 Recording and Documentation of Indications

Permanent records of the locations of all relevant indications (except those removed via grindings, etc., during the inspection process) shall be kept, and may be made by one of the following means:

a. Sketching the indication: The MT indication report form (Appendix D) requires sketches of indication location which should include an overall location on the structure and a specific location on the part.
b. Photographing the indication: If required by the owner, the indication should also be documented as follows:

1. Wide-angle photograph or video of the overall area.
2. Close-up photograph or video of the MT indication.
3. Close-up photograph or video with MT indication removed.

All such indications should be photographed against a white contrast background and contain a scale, and bear a means which uniquely identifies the indication's location.

8.9.2 Reports

A field report should be made available to the owner upon completion of the examinations. Level II MT personnel are considered to be responsible for ensuring that all necessary report requirements are completed before leaving the inspection site. The testing agency should retain a copy of the complete inspection report. The report should outline the following areas:

a. Welds inspected and MT technique used. (See the Magnetic Particle Examination Report.)
b. MT indications found, including interpretation. (See the Magnetic Particle Indication Report Form.)

8.9.3 Report Forms

Forms listed in 8.9.2 are provided in Appendix D as guidelines, and can be modified to meet the needs of the owner.

APPPENDIX A—EXAMPLE QUESTIONS FOR WRITTEN UT TEST

The following is a list of typical questions of appropriate severity to be used as a guide in formulating a written quiz to screen candidates for a practical UT examination. Questions in the written examination should be based on the particular operator's designs, material properties, and ultrasonic procedures.

1. The amount of energy reflected from a discontinuity will be dependent on:

a. The size of the discontinuity.
b. The orientation of the discontinuity.
c. The type of discontinuity.
d. All of the above.

2. Which of the following frequencies would probably result in the greatest ultrasonic attenuation losses?

a. 1.0 megahertz (MHz).
b. 2.25 megahertz (MHz).
c. 10 megahertz (MHz).
d. 25 megahertz (MHz).

3. An inclusion of lamination detected in plate inspected to ASTM Specification A435 is unacceptable when the length of continuous loss of back reflection cannot be contained within _________ diameter circle.

4. If two reflectors of the same size are observed with an ultrasonic instrument at different metal path distances, the reflector at the greatest distance will produce:

a. The greatest echo.
b. The same size echo.
c. The smallest echo.
d. None of the above.

5. A transfer correction may be employed to correct for differences in the reference standard and workpiece:

a. Contact surface curvature.
b. Contact surface roughness.
c. Acoustical impedance.
d. All of the above.
e. None of the above.

6. Ultrasonically transparent defects in welds are generally the result of:

a. Residual stresses.
b. The structure of the weld.
c. The difference between the base and filler metals.
d. Magnetic fields caused by the welding current.

7. A ⅛-inch diameter flat-bottom hole has been employed for calibration of an ultrasonic instrument. While scanning a forging, an imperfection is noted with an amplitude 6 decibels greater than the reference standard. The equivalent ideal flaw size of the imperfection is:

a. ¼-inch diameter.
b. ¾-inch diameter.
c. 0.024 square inch.
d. 0.078 square inch.

8. As frequency increases in ultrasonic testing, the angle of beam divergence for a given crystal diameter:

a. Decreases.
b. Remains unchanged.
c. Increases.
d. Varies uniformly through each wavelength.

9. Identification of a weld flaw is determined by:

a. The shape of the echo at maximum amplitude.
b. The number of spikes in the echo.
c. The number of decibel gain of the echo above the reference level.
d. All of the above.
e. None of the above.

10. The amplitude method of flaw size measurement is used only when the flaw:

a. Is larger than the ultrasonic beam cross section.
b. Is smaller than the beam cross section.
c. Has no dimension greater then four wave lengths.
d. Has all dimensions greater than four wave lengths.

11. The full skip distance of a 70-degree angle beam in a ⅝-inch thick plate is:

a. 2 3/16 inch.
b. 4 ½ inch.
c. 3 7/16 inch.
d. 1 ¼ inch.

12. Which angle is not recommended for a circumferential body wall inspection of a 24-inch diameter pipe with a ½-inch thick body wall?

a. 60 degrees.
b. 70 degrees.
c. 80 degrees.
d. All of the above.

13. Which of the following angles would produce the best results for detecting lack of side wall fusion in a "V" butt weld with a 30-degree bevel preparation?

a. 45 degrees.
b. 60 degrees.
c. 70 degrees.
d. 80 degrees.

14. The best ultrasonic inspection technique for detecting discontinuities oriented along the fusion line in a welded plate is:

a. An angle-beam technique employing surface waves.
b. A contact technique employing longitudinal waves.
c. An immersion technique employing surface waves.
d. An angle-beam technique employing shear waves.

15. Describe a method for determining the sound path skip distance in a 1-inch thick diagonal brace member for a 60-degree angle beam transducer when the local dihedral angle is 120-degrees.

16. Assuming the skip distance obtained in the above question was 6½ inches, what is the effective beam angle in the steel?

17. Construct a flaw location diagram for the inspection of a weld in ¾-inch thick plate using a 45-degree angle beam probe.

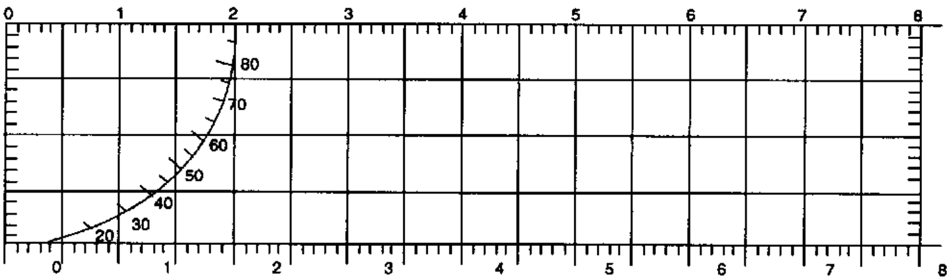


Figure A-1—Question 17 Diagram

18. Construct a flaw location for inspecting a longitudinal weld in pipe with an outside diameter of 10 inches and a wall thickness of 1 inch. Indicate the probe angle selected for the inspection.

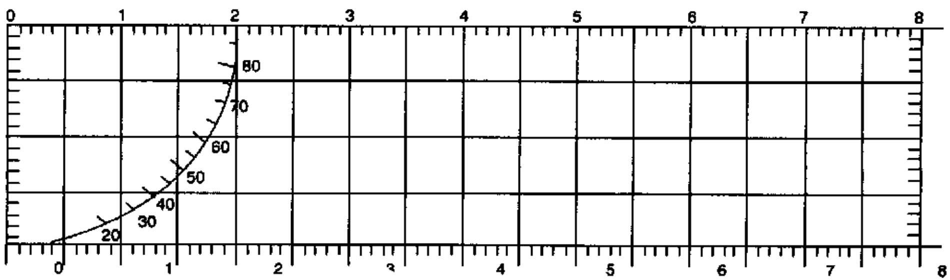


Figure A-2—Question 18 Diagram

19. Select one of the following and place the letter corresponding to the correct nomenclature for each of the arrows shown below.

a. Concave root.
b. Porosity.
c. Leg length.
d. Incomplete penetration.
e. Depth of penetration.
f. Slag.
g. Overlap.
h. Undercut.
i. Seam.
j. Incomplete fusion.
k. Back weld.
l. Heat-affected zone.
m. Crack.
n. Root bead.
o. Misalignment.
p. Weld cap.
q. Reinforcement.
r. Base metal.

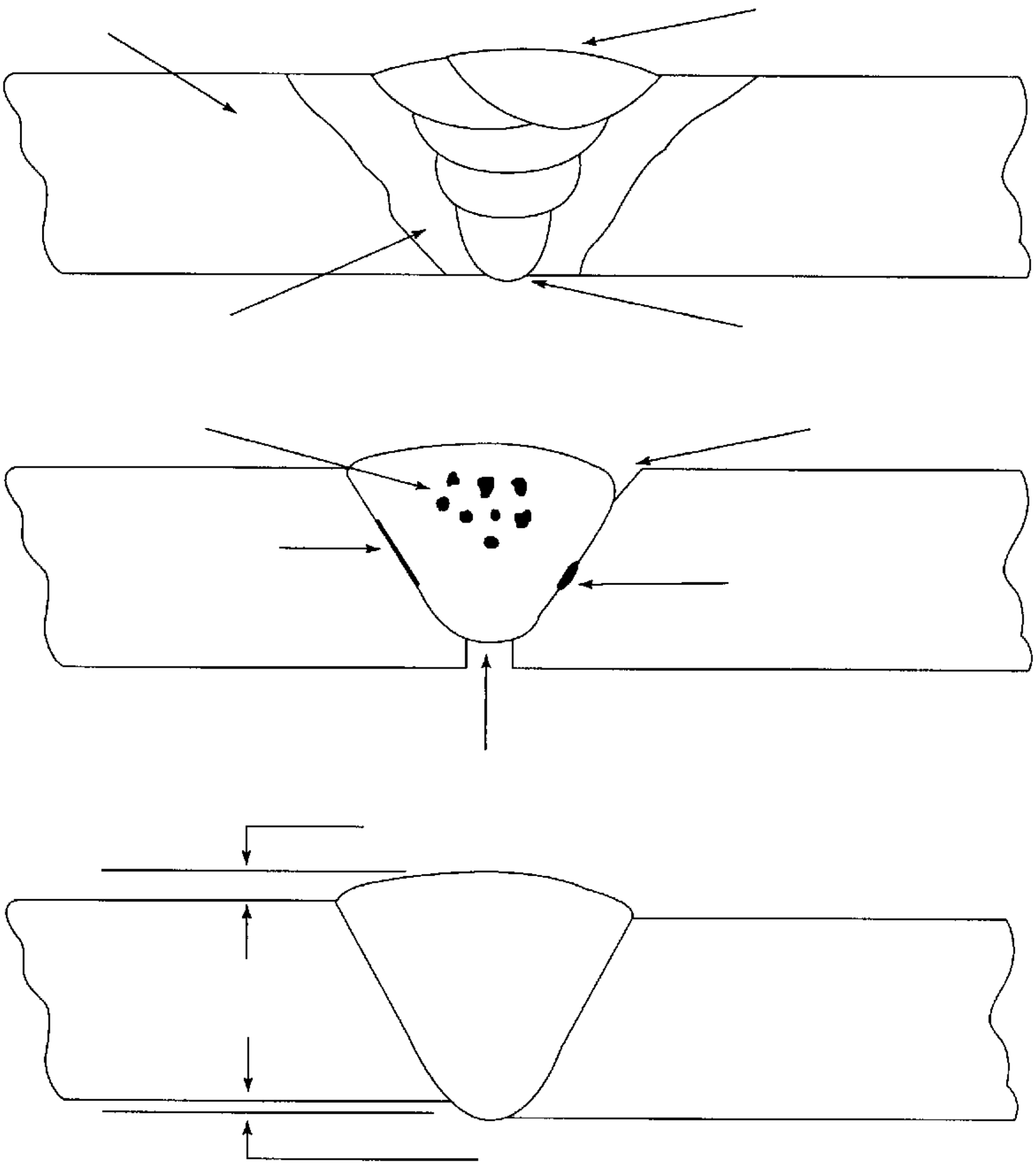


Figure A-3—Question 19 Diagram

APPENDIX B—CONSTRUCTION AND UT EVALUATION OF MOCKUP STRUCTURES

Mockup connections fabricated from tubulars of comparable diameters and wall thicknesses to the actual structure provide the full range of problems UT personnel will encounter during subsequent construction inspection. For structures designed and controlled to permit a Level-C flaw acceptance size, the mockup connection yields meaningful information; however, mockup connections are not recommended for screening to determine capabilities for Level-A inspections since surface irregularities are more apt to control the path of the fractured specimen than small internal flaws.

Several operators have fabricated and successfully employed mockup structures where the "can" was represented by 30-inch or larger tubular and "brace" members ranging from 12 inches to 24 inches in diameter. Each mockup should be constructed to contain at least one horizontal and a diagonal framed at the smallest dihedral intersection angle represented in the structural design. Minor member lengths should be at least 12 inches in length at the shortest point to ensure adequate scanning length in all positions.

It is suggested each member be indexed from some convenient point and the circumference of each member be clearly marked in one-inch increments as a common reference to any flaws detected during the test. Brace ends should be covered to block visual access to poor root conditions which may result in ultrasonic reflectors.

Evaluation of the candidate's performance using mock-up connections may require comparison with the ultrasonic specialist's evaluation of subsequent destructive testing which may be accomplished by sectioning each brace member into small circumferential segments from 2 inches to 3 inches in width. The position of the segment is selected from the candidate's reports as those locations indicated as defective. An equal length should also be selected and removed at random from areas considered to be free of imperfection as a test of missed defects. Segment removal may be by oxyacetylene cutting or by sawing, but in either case care must be exercised to avoid destruction of any defects present.

Each segment should be smoothed on the exposed weld faces and carefully examined by magnetic particle methods or visually after etching, to delineate the weld defects. At this time, the width of any defects noted can be measured and recorded on a master plot of the brace welds.

Following visual inspection of the edges, the sample is prepared for destructive testing by removal of the fillet reinforcement on the outside diameter (OD) surface of the weld. This may be accomplished by arc-air gouging or by grinding. If the majority of the indicated defects are in the 50 percent of the cross section near the root, reinforcement may be removed by arc gouging the complete circumference of the weld prior to segmentation.

To fracture the specimen, it should be placed in a fixture in a manner shown in Figure B-1 to permit application of a load on the inside diameter (ID) surface of the brace member segment. In the absence of laboratory equipment for this task, the specimen may be clamped in a sturdy vise and struck sharply with a heavy hammer.

In most cases the root notch acuity will be sufficient to cause fracture through the weld. If the root contour is exceptionally smooth (a rare occasion) and the weld metal is extremely tough, it may be necessary to chill each specimen in dry ice and alcohol or acetone before applying the load.

After fracture, each defect observed must be carefully measured and the results recorded on the master plot. Particular care must be exercised in evaluating lack-of-root fusion and incomplete penetration since the original position of the root face preparation is often indeterminate. The final plot of weld quality should subsequently be compared to the candidates report and a performance score developed in accordance with the method recommended in Section 5.

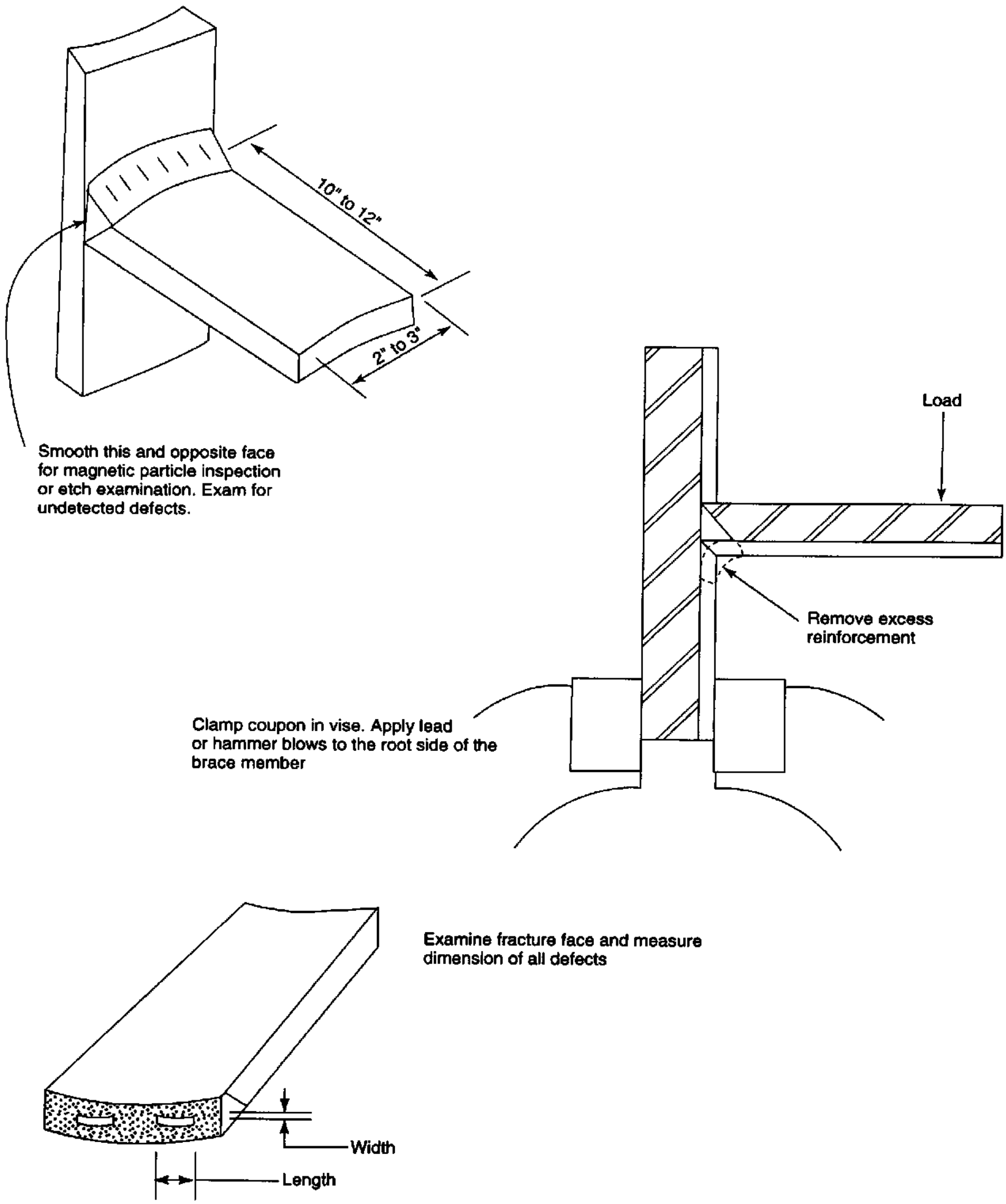


Figure B-1—Technique for Examining Welds Containing Natural Defects

APPENDIX C—EXAMPLE OF SCORING UT PERSONNEL PERFORMANCE

Figures C-1 and C-2 are typical examples of test plate and report records for the practical performance test. To evaluate the candidate's performance results by the formulas shown in 5.3.4, a graphical plot of the actual location of reflectors within the test plate and the candidate's indications should be prepared as shown in Figure C-3. The graphical plot will aid in determining the values of factors within the formulas and minimizes errors in evaluation. The results of the sample shown in Figure C-3 is as follows:

L_a = Length of all actual reflectors in the test plate
= $A + B + C + D$ = 5¼ inches (5.25)

L_c = Credited length for indications when the width and length are reported from one-half to twice actual dimensions. (Credit is given for the lesser of the reported length or actual length of the defect.)
= $A + c + d$ = 3⅜ inches (3.875)

L_i = Accumulative length of all indications
= $a + b + c + d + e$ =5⅞ inches (5.875)

L_f = Accumulative length of indications above the stated disregard level where no reflector exists
= e = ½ inch (0.5)

$$p = \frac{3.375}{5.25} \times 100 = 64.3$$

$$R = \frac{3.375}{5.875}[1 - (0.5/5.876)] \times 100 = 57.0$$

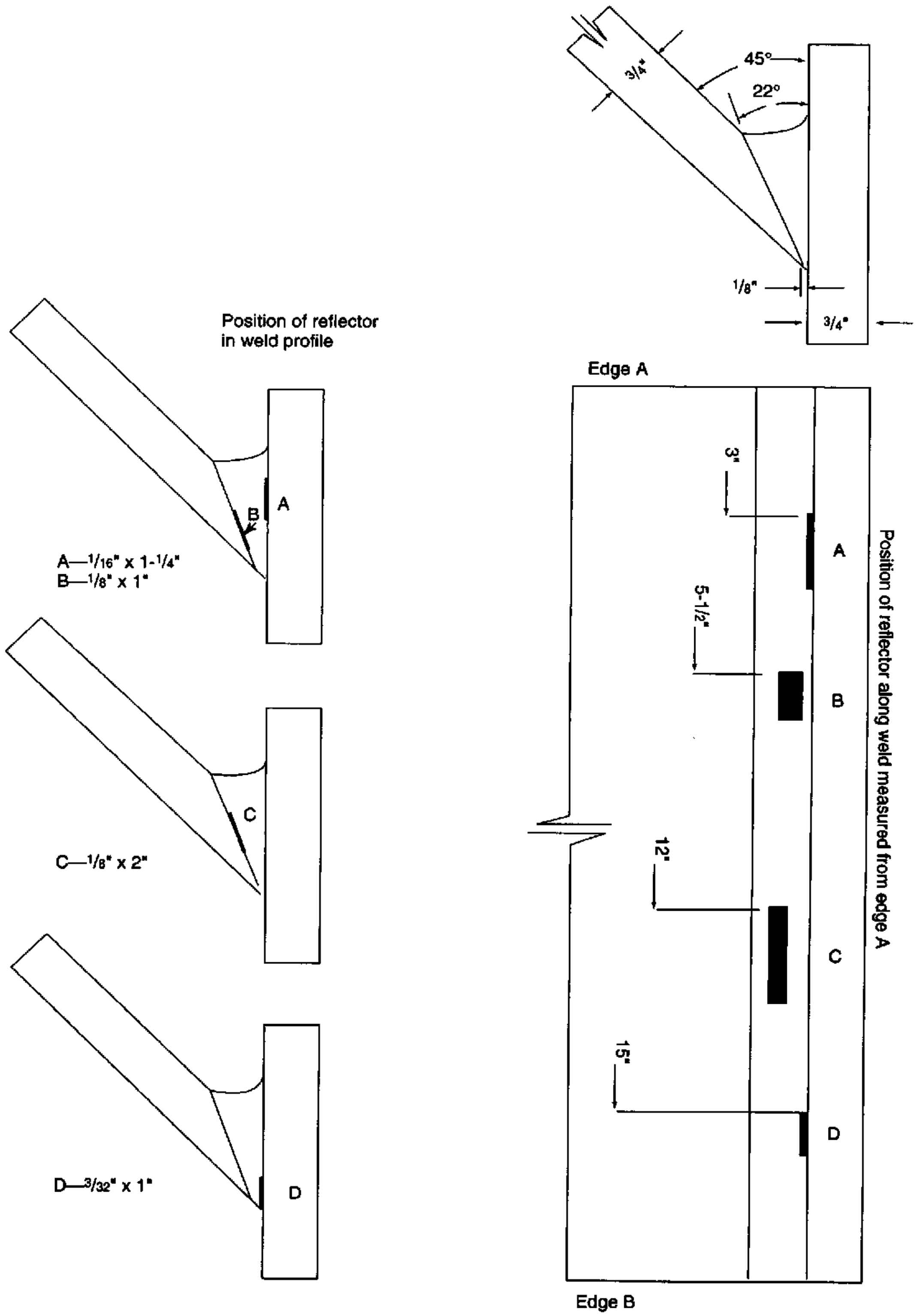


Figure C-1—Example of Key to Placement of Reflectors in Test Plate

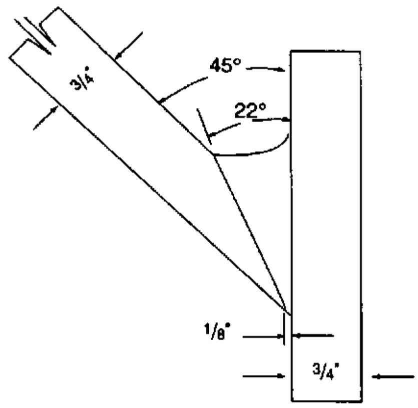
Name: ______________________

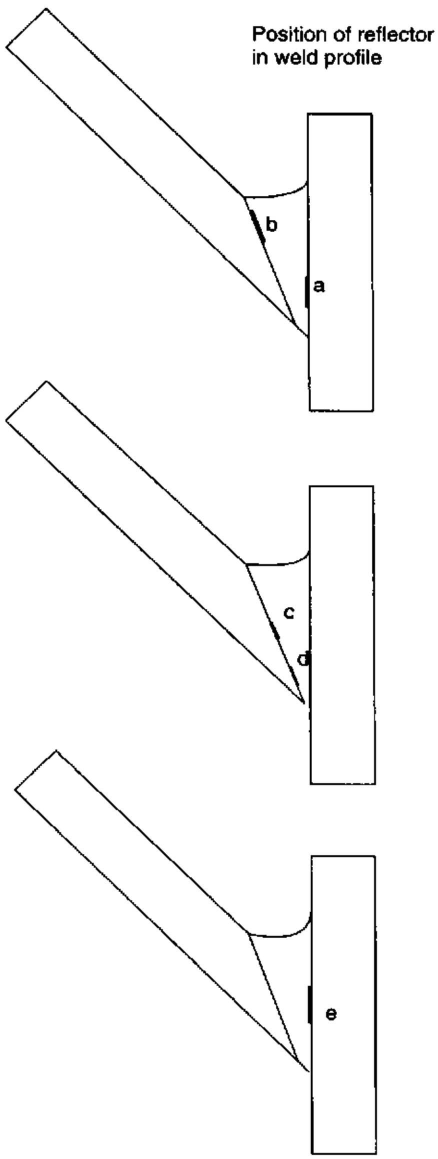
Company: ______________________

Test Plate No.: ______________________

Date: ______________________

Indicate position of defect on weld profile. Number or otherwise identify defect.





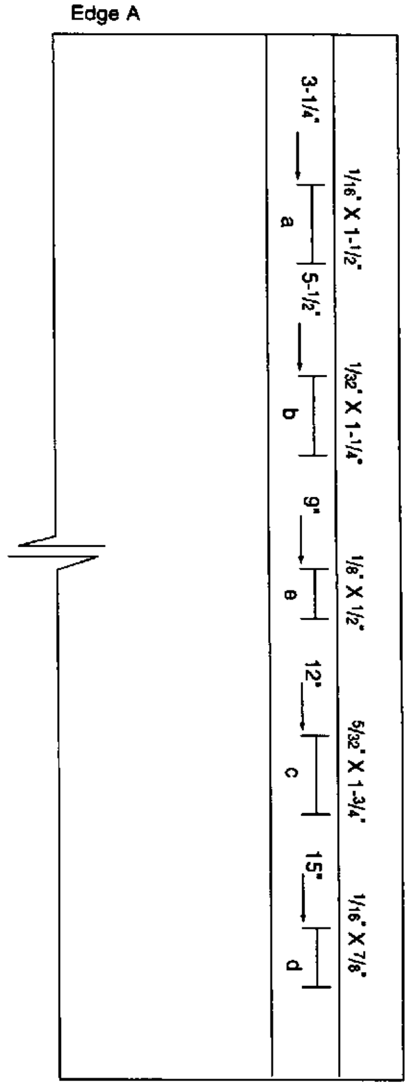


Figure C-2—Example of Typical Ultrasonic Technician Report of Test Results

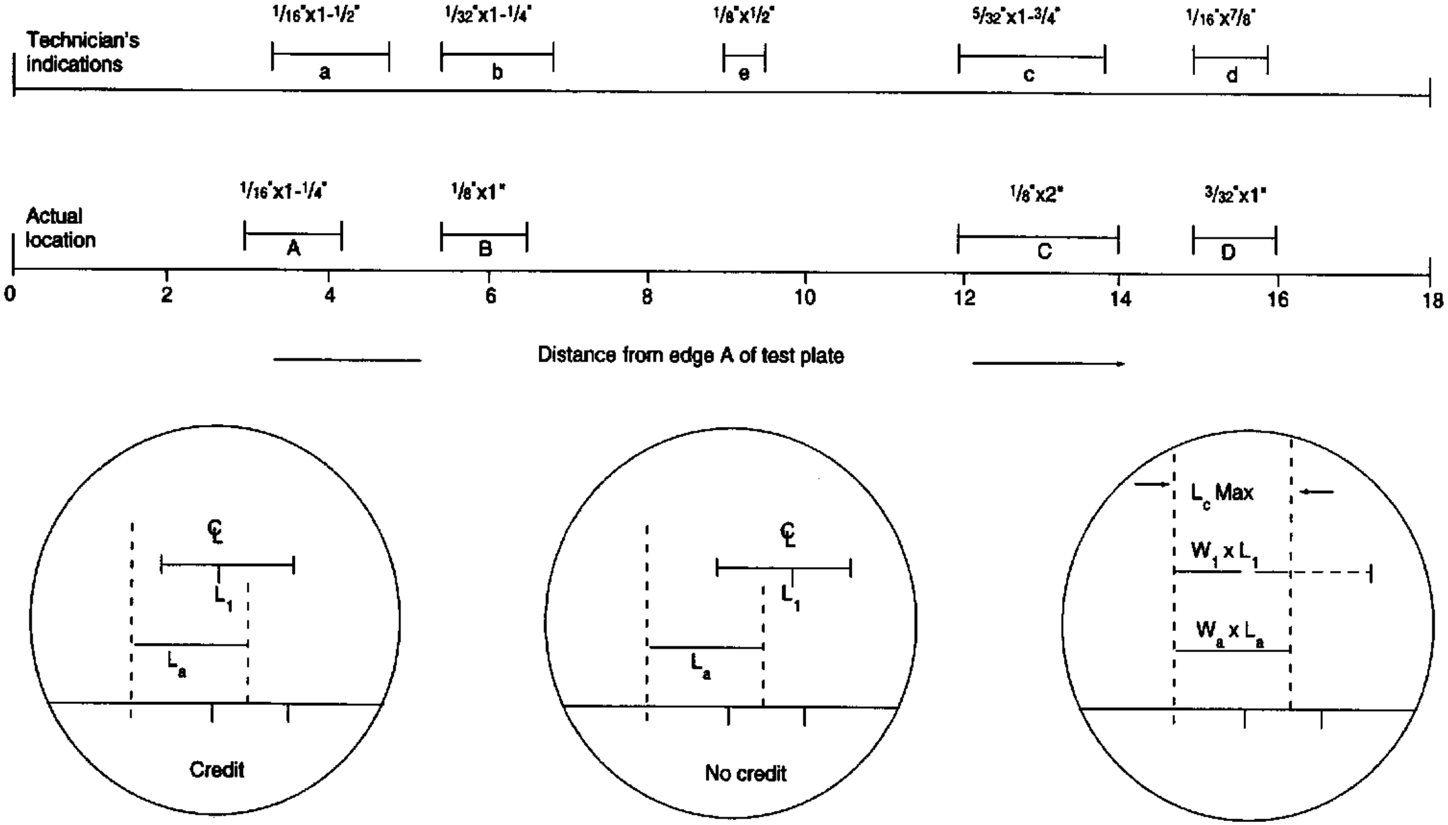


Figure C-3—Graphical Evaluation of Technician's Report

If centerline location of indication is inside boundary of L_a, or within 1/2" of the actual centerpoint of L_a (whichever is greater), credit is awarded for proper positioning. Otherwise, no credit is awarded regardless of dimensional accuracy of the call.

If W_1 and L_1 dimensions are indicated between one half and twice W_a and L_a, credit is awarded for L_1 to a maximum length equal to L_a.

APPENDIX D—EXAMPLES OF UT AND MT REPORT FORMS

ULTRASONIC EXAMINATION REPORT

API RP 2X

Report #:

Job No.:	Examination date: Page: of
Structure:	Material description:
Material Specification:	Surface preparation:
Couplant:	Instrument: S/N:

Probe	Angle	Mhz	Size	X: AL (S)	

Quality level

Procedure No.:

Drawing No.	Welding No.	Accept	Reject	Planar	Spherical	Cylindric	Transfer	Thickness	Inch local	Describe each indication. Draw full scale sketch for all rejected indications on Figure D-1. Identify all defects by weld number and clock position. Clock position (inch) clockwise from top looking at leg/chord with unit in installed position. Horizontal welds should always be indicated on the drawings.

Company Representative (technician): ____________________ Client Representative: ____________________

Signature/level: ____________________ Signature: ____________________

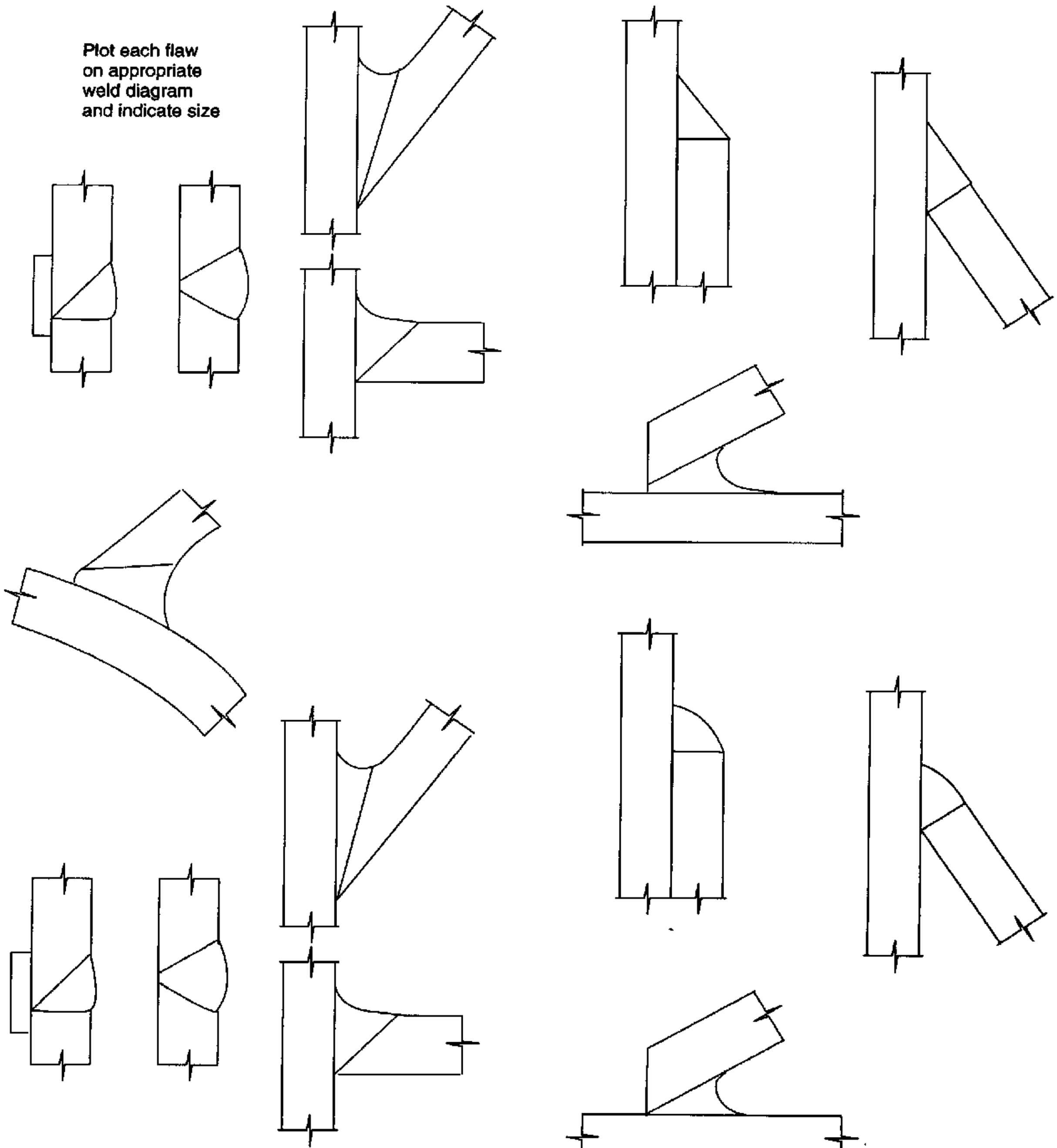


Figure D-1—Ultrasonic Examination Report Rejected Indications

MAGNETIC PARTICLE EXAMINATION REPORT

		Report:
Job No.	Examination date:	Page: of
Structure:	Material description:	
Material specification:	Surface preparation:	
Method magnetize:	Equipment:	
Prod/pole distance:	Sensitivity:	
Technique:	Illumination:	
Method demagnetize:	Heat treat status:	
Accept criteria:	Sts procedure:	
Cleaner:	Background:	Detect Media:

Item	Weld or Piece	NDE/ISO	Welding Process	ACC. REJ.	Comments

Company Representative (technician): ______________________ Client Representative: ______________________

Signature/level: ______________________ Signature: ______________________

MAGNETIC PARTICLE INDICATION REPORT FORM

Operator: ______________________ Date: ______________

Operator's representative: ______________________ Structure name: ______________

Agency: ____

Weld identification: ____

Location of indications: ____

Length: ____

Visually observable?: ____

Width (if visual): ____

Depth (if physically measured): ____

Depth (estimated on particle appearance): ____

Surface grinding: ______________________ Metal removed: ______________

Final evaluation: ____

Location on structure

Location on joint

Documentation: ____

Additional remarks: ____

MT personnel and qualifications: ____

APPENDIX E—GLOSSARY OF NONDESTRUCTIVE EXAMINATION TERMINOLOGY

A-scan: A method of data presentation on a cathode ray tube (CRT) or other visual presentation component which utilizes a horizontal base line to represent distance or time, and a vertical indication from the base line to represent amplitude. The horizontal distance between any two signals represents the distance in the material between the two conditions causing the signals.

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

acoustic impedance: The factor which controls the propagation of an ultrasonic wave at a boundary interface. It is the product of the material density and the acoustic wave velocity within the material.

agency: An organization, or part of an organization, selected by the owner or fabricator to perform examinations as required by the specification, contract, and/or purchase order.

agency personnel: Employed and trained by an independent organization and offered to the operator on a contract basis, for assisting in fabrication inspections and examinations.

amplifier: The component of an instrument which increases the strength of an electronic signal.

amplitude, echo: The vertical height of an A scan signal measured from base-to-peak or peak-to-peak.

angle beam: A wave train traveling at an angle, measured from the normal (perpendicular) to the test surface to the centerline of the sound base.

angle beam examination: An ultrasonic examination method in which the interrogating sound beam is injected into the part at an angle to the test surface.

angle beam probe: The combination of an angle beam transducer and a wedge (usually plastic) which will produce shear waves in the part under test.

angle beam transducer: The component of an electronic examination system containing a piezoelectric element which transmits or receives the acoustic energy used to perform the examination. The angle beam is not directly generated by the element, but is refracted at the wedge-specimen interface.

angle of incidence: The included angle between the line perpendicular to the examination surface and the axis of the sound beam in the part. Also referred to as the *beam angle*.

angle of reflection: The angle defined by the direction of the reflected wave and the normal (perpendicular) to the interface at the point of incidence. The angle of reflection is equal to the angle of incidence.

angle of refraction: The angle between the centerline of the angle beam and the normal (perpendicular) to the refracting surface.

attenuation: 1. The loss in acoustic energy which occurs between any two points of travel (due to absorption, reflection, etc.). 2. The controlled reduction in sensitivity within the instrument.

attenuator: A component between the signal source and amplifier which reduces the amplitude of the signal, usually calibrated in decibels (dB).

B-scan: A method of data presentation on a cathode ray tube (CTR) to represent depth of an indication in the material being examined, as seen from the side of the material.

back reflection: The signal received from material discontinuities or other reflecting surfaces.

background noise: Extraneous signals caused by signal sources within the ultrasonic system, reception of outside electromagnetic interference, or anomalies within the part under examination. Sometimes referred to as grass.

base line: The horizontal trace across the cathode ray tube which represents time or distance.

beam angle: The angle between a line perpendicular to the examination surface and the axis of the sound beam in the part. Also referred to as *angle of incidence*.

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

bevel angle: The angle of the weld preparation of a member to be welded.

boundary echo: A reflection of an ultrasonic wave from an acoustical interface.

C-scan: A method of data presentation on a cathode ray tube (CRT) which represents the presence and size of an indication in the material being examined, as seen from the examination surface of the material.

calibration: The act of checking and resetting NDE equipment's internal and external controls at regular intervals so that the instrument functions within the accuracies and tolerances of the equipment manufacturer, the operator's written procedure, and certain nationally or internationally published standards.

cant angle: The orientation of the sound beam relative to the axis of the member being examined.

clock position: A method for discontinuity location/orientation reporting. Defined as rotation measured in inches clockwise from the top (12:00 o'clock) position of each brace/leg looking at the leg or chord with the structure in the installed position. For horizontal chords (for example, vertical braces), 12:00 o'clock position should always be indicated on the drawings.

compressional wave: A wave in which the particle motion or vibration is in the same direction as the travel of the wave (longitudinal wave).

continuous method (MT): The method in which magnetic particles are applied and removed from the part and an interpretation performed while the magnetizing device is energized.

contact examination: The method in which the search unit makes direct contact with the material through a thin couplant.

contact transducer: A transducer which is coupled to a test surface either directly or through a thin film of couplant.

continuous wave: A constant flow of ultrasonic waves, as opposed to intermittent pulses.

control echo: A reference signal from a constant reflecting surface such as a back-wall reflection.

corner effect: The reflection of a sound beam directed normal to the intersection of two perpendicular planes.

couplant: A medium which transfers ultrasonic sound waves between the transducer and the part being examined. Since ultrasonic sound waves do not travel through air, a couplant is usually a liquid.

crack: The separation of metal caused by improper welding, stress, fatigue, or inadequate design strength. A planar fracture-type discontinuity characterized by a sharp tip, and when nonvisual, typically has a relatively high ratio of depth to width.

critical angle: The incident angle of the sound beam beyond which a specific refracted mode of vibration no longer exists.

critical flaw: A flaw which is capable of causing failure.

cross talk: An unwanted condition in which acoustic energy is coupled from the transmitting crystal to the receiving crystal without propagating along the intended path through the material.

CRT: Cathode Ray Tube. The visual interface of an electronic instrument.

crystal: The piezoelectric element in a transducer.

DAC: Distance Amplitude Correction. A method (either manual or electronic) of correcting for the changes in the ultrasonic wave caused by attenuation or divergence.

damping (transducer): A method of limiting the duration of vibration in the search unit by either electronic or mechanical means.

damping (ultrasonic): The decrease or decay of the amplitude of ultrasonic waves with respect to time.

dead zone: The un-inspected area or distance in the part directly beneath a transducer in which any reflection is masked by the noise generated by the crystal.

decibel (dB): The unit for measuring the strength or amplitude of sounds, or ultrasounds. A change of 6 dB will double or halve the strength of amplitude.

defect: A discontinuity whose indications (for example width and length) do not meet the specified acceptance criteria. The term designates rejectability.

delayed sweep: A means of delaying the start of the horizontal sweep on a CRT, thereby eliminating the presentation of early response data.

delta effect: Acoustic energy reradiated by a discontinuity.

designer: The person, firm, corporation, or other organization employed by the owner/operator to develop the design, details, and specifications for the facility.

detection: The process of discrimination by which a discontinuity is observed and reported against some background.

diffraction: The deflection of a wave front when passing the edges of an obstacle.

diffuse reflection: Scattered incoherent reflections caused by rough surfaces or associated interface reflections of ultrasonic waves from irregularities of the same order of magnitude or greater than the wave length.

discontinuity: A detectable interruption in a material which may or may not have an undesirable effect on the integrity of the fabricated part.

dispersion, sound: Scattering of an ultrasonic beam as a result of diffuse reflection from a highly irregular incident surface.

divergence: The normal spreading of ultrasonic waves after leaving the search unit. A function of the crystal element size, frequency and shape.

dual search unit (twin probe): A search unit containing two piezoelectric elements, one a transmitter and the other a receiver, separated by an acoustic barrier (T-R, S-E).

dual transducer methods: Methods of ultrasonic examination in which separate transducer and receiving crystals are used. Both elements may be combined in one search unit or may be two separate units.

dynamic range: The ratio of maximum-to-minimum relative areas that can be distinguished on the cathode ray tube at a constant gain setting.

echo: Reflected energy or the indication of reflected energy as presented on the CRT.

effective beam angle: The true angle of a sound beam when its centerline is plotted on a flat plane as opposed to elliptical or curved surfaces.

effective penetration: The maximum depth in a material at which the ultrasonic transmission is sufficient for effective detection of discontinuities.

electrical noise: The undesirable extraneous radiated or directly-coupled signals caused by internal or external electrical circuits. This is sometimes referred to as electromagnetic interference (EMI).

electromagnet: A soft iron core surrounded by a coil of wire which, when energized, creates a magnetic field.

engineer: A responsible person who acts on behalf of the owner during design or construction operations.

evaluation: A review, following interpretation of the indications noted to determine whether they meet specified acceptance criteria. This usually refers to the ability to relate an indication to some quantifiable dimension.

fabrication crack: A crack which occurs during fabrication as the result of improper welding procedures or technique.

face of weld: The exposed surface of a weld on the side from which the welding was done.

false indication (MT): An indication which is formed in the absence of any significant flux leakage, typically due to mechanical entrapment and/or gravity. The incorrect evaluation of a visual or magnetic particle indication. For example, evaluating undercut as a crack.

false positive indication: An indication which is incorrectly evaluated as being relevant when it is actually non-relevant.

false negative indication: An indication which is incorrectly evaluated as being non-relevant when it is actually relevant.

far field: The region beyond the near field in which the relative strength of the sound wave can be predetermined.

flaw: A discontinuity in an otherwise sound material. The term flaw may refer to an undesirable condition but does not necessarily infer rejection.

flux density: The number of magnetic lines of force in an area at right angles to the direction of field.

focused beam: The converging of the sound beam at a specified distance, usually effected by shaping the crystal or using an acoustic lens.

focused transducer: A transducer with a concave face which converges the sound beam to a focal point or line at a predetermined distance within the part.

fracture control plan: A plan by which design options, material selections, fabrication control, inspection procedures, and examination procedures are integrated into a consistent strategy.

fracture mechanics: An engineering discipline which may be used to deal with the local stress state near planar discontinuities and with the growth of cracks.

frequency (fundamental): In resonance examination, the frequency at which the wavelength is twice the thickness of the examined material.

frequency (examination): The effective ultrasonic wave frequency of the system used to examine the material.

frequency (pulse repetition): The number of pulses per second.

gain: Controlled adjustment of sensitivity within the instrument.

gap scanning: Short fluid column coupling technique (water column).

gate: An electronic component used to monitor specific segments of time, distance, or amplitudes.

gauss: Unit of flux density or induction. It refers to the induced field inside a part. One gauss equals one line of flux per centimeter of area. It is designated by the symbol "B."

gauss meter: A measuring instrument which uses a Hall-effect sensor to measure oersted or gauss.

ghost: An irrelevant indication which has no direct relation to reflected pulses from discontinuities in the material being examined.

grazing incidence: The effect of a beam directed towards a part at a glancing angle to the test surface during immersion testing.

harmonics: vibration frequencies which are integral multiples of the fundamental frequency.

hash: Numerous, small indications appearing on the cathode ray tube of the ultrasonic instrument indicative of many small heterogeneities in the material or background noise (also referred to as grass).

hertz (Hz): A frequency measurement of one cycle per second.

impedance (acoustic): The resistance to flow of ultrasonic energy in a medium. A product of particle velocity and material density.

included angle: The total opening of a weld preparation. The sum of two weld preparations.

incomplete fusion: The non-coalescence of weld metal with the sidewall (lack of sidewall fusion) or between successive weld passes.

indication (general): The evidence of a discontinuity that requires interpretation to determine its significance.

indication (UT): A signal displayed on the cathode ray tube of an ultrasonic instrument.

initial pulse: The first indication which may appear on the cathode ray tube. It represents the shock of the transducer crystal by the transmitter (main bang).

inspector: An individual representing the owner whose function is to ensure that the fabrication is built according to the controlling specifications.

interface: The physical boundary between two adjacent surfaces or components.

interpretation: The determination of whether indications are relevant or non-relevant.

lamellar tearing: A model of failure in welded steel construction in which cracking develops under the weld in the parent material due to the combined effects of high stresses in the Z-direction (through thickness) and low ductility in the Z-direction caused by nonmetallic inclusions.

lamination: A metal defect with separation or weakness generally aligned parallel to the worked surface of the metal.

linear indication (MT): An indication which is line like in appearance. An indication which may have the visual appearance of a crack and which may or may not be an actual crack.

linearity (amplitude): The characteristic of an ultrasonic examination system indicating its ability to respond in a proportional manner to a range of echo amplitudes produced by specified reflectors.

linearity (distance): The characteristic of an ultrasonic examination system indicating its ability to respond in a proportional manner to a range of echo signals produced by specified reflectors, variable in time, usually a series of multiple back reflections.

local dihedral angle: The angle between tangent surfaces at a given point along a weld joining two curved surfaces.

longitudinal indication (MT): Indication which is oriented parallel with the weld.

longitudinal wave: A wave in which the particle motion or vibration is in the same direction as the travel of the wave (compressional wave).

magnetic aspect ratio: The ratio of depth to width; typically, the greater the aspect ratio, the greater the flux leakage.

magnetic field indicator: A device used to locate or determine the relative intensity of an applied flux leakage field.

magnetic particle indication: The presence of a buildup of magnetic particles.

markers: A series of electronically-generated indications on the horizontal trace in increments of time or distance.

material noise: Extraneous signals caused by the structure of the material being examined.

metal path distance: The actual one-way travel distance between the transducer exit point and a reflector.

mode: The manner in which acoustic energy is propagated through a material as characterized by the particle motion of the wave (see *compressional wave* and *shear wave*).

mode conversion: The characteristic of surfaces to change the mode of propagation of acoustic energy from one mode to another.

mode of vibration: See *mode*.

multiple back reflections: See *multiple reflections*.

multiple reflections: The repetitive echoes from the far boundary of the material being examined.

near field: The distance in a material from the surface to the nearest depth of accurate inspection (see far field).

node: A point in a standing wave where a given characteristic of the wave field has zero amplitude.

noise: Any undesirable signal that tends to interfere with the normal reception or processing of the desired signal. The origin may be electrical or mechanical, or from small material reflectors.

non-relevant indication: An indication that has no relation in a discontinuity that might constitute a defect.

non-relevant MT indication: The buildup of particles caused by magnetic properties of the part which do not indicate a change in material strength. For example, indication formed at the boundary of two different magnetic permeability.

notch effect: A stress raiser caused by a notch-like discontinuity such as undercut or convex weld profile.

operated: The unit of field strength which produces magnetic induction. Its designation is the letter H.

operator (ultrasonic): Personnel employed to carry out ultrasonic examination and evaluation.

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

orientation: The angular relationship of a surface, plane, discontinuity axis, and so forth, to a reference plane or surface.

oscillogram: A common term for a photograph of data displayed on a cathode ray tube.

overlap: The protrusion of the weld beyond the toe of the weld.

penetration (ultrasonics): The propagation of ultrasonic energy through a material (see *effective penetration*).

penetration: The depth in a material from which indications can be located and measured.

piezoelectric effect: The characteristic of certain natural and man-made materials to generate electrical charges when subjected to mechanical vibration or force and, conversely, to generate mechanical vibrations when subjected to electrical pulses.

pitch-catch: See *dual transducer methods*.

pole: The area on a magnetized part from which the magnetic field is leaving or returning into the part.

presentation: The method used to show ultrasonic wave information. (See *A-scan*, *B-scan*, *C-scan*).

probe: See *search unit*.

propagation: Advancement of a wave through a medium.

pulse: A short burst of mechanical or electrical vibrations.

pulse-echo: A single crystal ultrasonic examination method that both generates ultrasonic pulses and receives the reflected energy.

pulse length: The time duration of the pulse from the search unit.

pulse tuning: An electronic component of some instruments used to optimize the response of the search unit and cable to the transmitter by varying the frequency.

qualified personnel: An individual whose performance has been examined and found to be adequate for performance of the designated examinations.

qualitative: Pertaining to the quality of a material: for example, heavy, versus light, particle buildup.

quantification: The act of quantifying, that is, giving a numerical value to a measurement.

random sampling: A prescribed number of units selected by the inspector from a lot for inspection, such as one-in-ten, 10 percent, 20 percent, and so forth.

range: 1. The maximum ultrasonic path length that can be displayed. 2. The extent of variation in size; smallest-to-largest. (See also *sweep*).

reference block(s): A block, or series of blocks, containing artificial or actual discontinuities of one or more reflecting areas at one or more distances from the test surface, which are used as a test standard for reference in calibrating instruments and to aid in defining the size, shape, and distance of reflectors in materials.

reflection: See *echo*.

reflector: Any condition, not necessarily a discontinuity, capable of returning ultrasonic energy to the transducer.

refraction: 1. The characteristic of a material to change the direction of acoustic energy as it passes through an interface into another material. 2. A change in the direction, mode, and velocity of acoustic energy after it has passed an acute angle through an interface into a material with significantly different acoustic properties.

refractive index: 1. The ratio of the velocity of a wave in one medium to the velocity of the wave in a second medium with respect to the first. 2. A measure of the amount a wave will be refracted when it enters the second medium after leaving the first.

reject (suppression): An electronic adjustment on the ultrasonic instrument for reducing or eliminating low amplitude signals (electrical or material noise) so that larger signals are emphasized.

relevant indication: An indication from a discontinuity requiring evaluation. A relevant indication usually implies a rejectable discontinuity.

relevant MT indication: The presence of a magnetic particle indication which, when judged by a specific set of criteria, is typically rejectable or reportable.

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

reportable indication: Discontinuity which falls within a specified set of criteria and must be reported although it may not necessarily be a rejectable discontinuity.

resolution: The ability of ultrasonic equipment to present, simultaneously, separate indications from discontinuities, at nearly the same distance from the transducer, having nearly the same lateral position with respect to the beam axis.

rf (radio frequency) presentation: The unrectified display of the ultrasonic energy.

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

saturation (scope): A term used to describe an indication of such a size as to reach full-screen amplitude (100 percent). Beyond this point there is no visual display to estimate the actual height of the response signal.

scanning: The relative movement and motion of the search unit over a test piece.

scattered energy: Energy that is reflected in a random fashion by small reflectors in the path of a beam of ultrasonic energy.

scattering: Dispersion of ultrasonic waves in a medium due to causes other than absorption.

search unit: A device incorporating one or more piezoelectric elements. Also commonly known as *transducer* or *probe.*

send-receive transducer: See *dual search unit.*

sensitivity (UT): 1. The ability of the ultrasonic system to detect small discontinuities. 2. The level of amplification at which the receiver circuit of an ultrasonic instrument is adjusted.

sensitivity (MT): The minimum size discontinuity which a nondestructive testing technique can detect given specific procedures, equipment, personnel, and operating environment. Included in sensitivity is the degree that the technique can produce false alarms.

sensitivity (NDE Test): The capability of a NDE system to produce indications which can be interpreted and evaluated to an acceptance criteria. Test sensitivity usually implies detection in terms of a minimum quantifiable indication.

shadow: The portion of the sound beam which is interrupted by a discontinuity between the search unit and the volume of the material to be examined.

shear wave: The wave in which the particles in the medium vibrate in a direction perpendicular to the direction of propagation.

signal-to-noise ratio: The ratio of amplitudes of indications from the smallest imperfection considered significant and those caused by random factors such as grain size and extraneous energy.

single-leg technique: An electromagnet in which only one pole (single leg) is used to contact the part to induce a magnetic field.

skew angle: The angle by which the beam deviates right or left relative to its normal path in front of the transducer, due to the effects of curvature of the part being examined.

skip distance: The surface distance required for an angle sound beam to traverse the metal thickness, be reflected from the far side, and return to the original surface.

specialist: See *ultrasonic specialist.*

specific acoustic impedance: The characteristic of a material which acts to determine the amount of reflection which occurs at an interface. It represents the product of the density of the medium in which the wave is propagating and the wave velocity.

standardization: The act of checking that the instrument exhibits the needed accuracy prior to performing a specific examination and setting up the instrument to perform the examination using the relevant standard.

standing wave: A wave in which the energy flux is zero at distances equal to one-half the wavelength. Such waves in elastic bodies result from the interaction of similar trains of waves running in opposite directions and are usually due to reflected waves meeting those which are advancing.

straight beam: See *compressional wave.*

stress raiser: A notch, hole, or other discontinuity in contour or structure which causes localized stress concentration.

surface distance: The surface projection of metal path distance.

subject indication: Indication evaluated as relevant in which the confidence level is questionable and may require supplemental testing for further interpretation or evaluation.

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

TCG: Time Controlled Gain circuitry in some ultrasonic instruments which compensates for attenuation losses in the material. Designed to negate the need for manually devising distance amplitude correction curves.

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

through-transmission: A dual transducer method using two transducers in which the ultrasonic vibrations are emitted by one transducer and received by the other transducer on the opposite side of the part. The ratio of amplitudes of received signals is used as the criterion of soundness.

toe of weld: The junction between the face of a weld and the base metal.

transducer: An electro-acoustical device for converting electrical energy into acoustical energy and vice versa. See *search unit.*

transfer mechanism: A technique or procedure used to account for the effects of differences in surface texture, curvature, coatings, and other variations between the reference standard and the workpiece.

transmission angle: The incident angle of the transmitted ultrasonic beam. When the ultrasonic beam is perpendicular to the test surface, the transmission angle is zero degrees.

transverse indication: Indication which is oriented 90 degrees to the weld toes.

transverse wave: See *sheer wave.*

two crystal method: See *dual transducer methods*.

ultrasonic: Mechanical vibrations having a frequency greater than approximately 20,000 hertz. Above the range of human audio response.

ultrasonic absorption: The dampening or decrease of ultrasonic vibrations that occurs when the wave traverses a medium.

ultrasonic examination: The evaluation of materials and fabrications using electronic methods for the purpose of locating and sizing discontinuities in materials and welds, and then reporting such findings for determination of compliance with the acceptance criteria.

ultrasonic indication: A commonly used term referring to the response of any ultrasonic energy presented on the CRT. It may or may not be from a discontinuity.

ultrasonic procedure: The detailed written description of the specific necessary steps and techniques which must be performed to provide an adequate examination and evaluation when using the ultrasonic method to determine structural integrity.

ultrasonic reflection: See *ultrasonic indication.*

ultrasonic specialist: An individual with extensive experience in the preparation and application of ultrasonic examination procedures. (Individuals certified by a nationally-recognized organization for the qualification of ultrasonic personnel to a grade equivalent to Level III of the American Society for Nondestructive Examination Certification.)

ultrasonic spectrum: The frequency span of elastic waves greater than the highest frequency audible to humans, generally regarded as being higher in the frequency range than 20,000 hertz up to approximately 100,000,000 hertz.

undercut: A groove of depression in the toe of the weld.

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

velocity (UT): The speed at which sound waves propagate through a medium.

vertical link: The maximum readable level of vertical indications determined either by an electrical or a physical limit of an A-scan presentation.

video presentation: The rectified rf signal on the cathode ray tube.

wave front: A continuous surface drawn through the most forward points in a wave disturbance which have the same phase.

wave length: The distance in the direction of propagation of a wave for the wave to go through a complete cycle. The wave length is dependent upon the mode of propagation and the material in which the wave is traveling.

wave train: A succession of ultrasonic waves arising from the same source, having the same characteristics, and propagating along the same path.

wedge: A specially-shaped device used to direct ultrasonic energy into the material at an angle.

yield profile: The shape of the weld face. Classes by AWS are "preferable, acceptable, and unacceptable." An example of unacceptable weld profile is excessive convexity.

yoke: A U-shaped electromagnet that induces a field in the part being tested. For complex geometries, the legs are articulated to allow for adjustment to geometry.

APPENDIX F—BIBLIOGRAPHY OF BACKGROUND REFERENCES

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