

**AWS B1.10M/B1.10:2016**  
**An American National Standard**

# **Guide for the Nondestructive Examination of Welds**



**AWS B1.10M/B1.10:2016  
An American National Standard**

**Approved by the  
American National Standards Institute  
August 29, 2016**

# **Guide for the Nondestructive Examination of Welds**

**5th Edition**

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Prepared by the  
American Welding Society (AWS) B1 Committee on Methods of Inspection

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## **Abstract**

This guide acquaints the user with the nondestructive examination methods commonly used to examine weldments. The standard also addresses which method best detects various types of discontinuities. The methods included are visual, liquid penetrant, magnetic particle, radiographic, ultrasonic, electromagnetic (eddy current), and leak testing.



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## Foreword

This foreword is not part of this standard but is included for informational purposes only.

The *Guide for the Nondestructive Inspection of Welds* was first prepared by the AWS B1 Committee on Methods of Inspection in 1977. The next edition was published in 1986, with updates to current industry practices. The 1999, 2009 and this current edition incorporate an overall edit and improvements to the figures. This fifth edition, B1.10M/B1.10:2016, *Guide for the Nondestructive Examination of Welds*, includes the above referenced changes and others notated with a vertical line along the side of the page.

The purpose of this guide is to give the reader an overview of the more common examination methods available without unnecessary detail and to provide an aid in deciding which method is generally best suited for the examination of a given weld.

The words examination, evaluation, inspection, and testing are considered synonymous when describing various nondestructive examination methods.

This guide has been prepared by the AWS B1 Committee on Methods of Inspection to serve as a simple but reliable source of general information. It is not intended that this document provide complete and comprehensive coverage of the subject. There are many reference manuals available. For more comprehensive coverage of the activities of the welding inspector, this guide should be used in conjunction with the AWS *Welding Inspection Handbook*, which provides a more thorough description of the duties and responsibilities of welding inspectors, the techniques and characteristics of the usual nondestructive examination methods, and the major aspects of sampling and documentation required for an adequate quality control system. For other references on the subject of inspection, refer also to the technical documents suggested in Clause 2, Normative References, and Annex E, Informative References. Annex A summarizes the required equipment, applications, advantages, and limitations of each of the seven examination methods covered in the document. Annex B is adapted from Part C—Nondestructive Examination Symbols of AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Annex C provides a list of typical application standards and the addresses of the standards developers. Annex D provides guidelines for requesting an official interpretation of an AWS standard.

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# Guide for the Nondestructive Examination of Welds

## 1. General

**1.1 Scope.** This standard provides a reference guide for the kinds of nondestructive examination methods that are used to verify that welds meet the requirements of a code or specification. The nondestructive examination methods described are:

- (1) Visual (VT)
- (2) Liquid Penetrant (PT)
- (3) Magnetic Particle (MT)
- (4) Radiographic (RT)
- (5) Ultrasonic (UT)
- (6) Electromagnetic (Eddy Current) (ET)
- (7) Leak (LT)

The types of discontinuities detected with each method and their causes are discussed. Acceptance criteria are not addressed in this standard. Requirements for nondestructive examination and acceptance criteria should be specified in procurement documents prior to the award of contracts.

Principal factors to consider when choosing an examination method are the advantages and limitations of the method, anticipated type and size of discontinuity, acceptance standards, and cost. Annex A is a guide to process selection.

**1.2 Advantages and Limitations of the Examination Method.** The advantages and limitations of the examination method help to determine which method(s) is (are) best for detecting discontinuities of a particular size, shape, and orientation. For example, radiography can detect discontinuities with major planes aligned parallel with the radiation beam, such as cracks oriented normal to material surfaces. Radiography, however, usually cannot detect laminations in material or cracks oriented parallel to the plate surface. Conversely, ultrasonic examination can detect cracks oriented in any direction provided the sound beam is oriented essentially perpendicular to the major axis of the crack.

**1.3 Acceptance Standards.** The statement “the weld shall be radiographically examined” is incomplete unless acceptance standards are specified. Acceptance standards define characteristics of discontinuities. They also establish upper and lower limits that determine the acceptance or rejection of a given discontinuity in conformance with the applicable acceptance standard. Discontinuities may be acceptable providing their size and distribution are within specified limits. Some acceptance standards are shown in Annex C.

**1.4 Cost.** Costs of the various examination methods depend on the particular situation. Two factors that should be considered in selection of a nondestructive examination method are the cost of performing the examination and of the equipment.

Visual examination is usually the least expensive, but it is limited to the detection of surface discontinuities. In general, the cost of radiography, ultrasonic, or eddy current examination is higher than the cost of visual, magnetic particle, or liquid penetrant examination. To determine the method(s) that will best satisfy the intended purpose and minimize cost, qualified personnel should be consulted.

**1.5 Procedures.** It should be recognized that all NDE methods must be performed in accordance with an approved procedure which is available to the technician performing the test or examination. This is almost always a requirement of the applicable code. Only by following a documented (written) procedure can the NDE technician ensure adherence to codes and specifications applicable to the fabrication under test. These procedures should be documented to provide all details of test preparation, performance, and interpretation to ensure reliability and reproducibility of results.

**1.6 NDE Symbols.** The use of NDE symbols and abbreviations is shown in Annex B, which is adapted from AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

**1.7 Standard Units of Measurement.** This standard makes use of both the International System of Units (SI) and U.S. Customary Units. The latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

**1.8 Safety and Health.** Safety issues and concerns are beyond the scope of this standard and therefore are not fully addressed herein. Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

U.S. Department of Labor Regulations:

- (1) CFR-29, Part 1910.107 *Spray Finishing using Flammable and Combustible Liquids*.

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

## 2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting and Thermal Spraying*

American National Standards Institute (ANSI) documents:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

## 3. Terms and Definitions

The terminology used in this guide is that established in AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting and Thermal Spraying*. Nondestructive examination (NDE) is a general term used in this text to identify the common examination methods used for evaluation of welds and related materials without destroying their usefulness.

AWS has chosen nondestructive examination (NDE) as the preferred terminology for these inspection methods. In other standards, literature, and industry usage, other expressions are commonly used. Among these are: nondestructive

evaluation (NDE), nondestructive inspection (NDI), and nondestructive testing (NDT). It must be emphasized that all of these expressions are commonly used and may be considered equivalent.

## 4. Discontinuities

**4.1 Discussion of Discontinuities.** The goal of nondestructive examination is to identify anomalies or irregularities for evaluation; irregularities as distinguished from the overall examination area. To the trained eye, irregularities will appear to “break” the relative uniformity or “continuity” of the examination area. Along with evaluation come considerations for accepting those discontinuities or rejecting them. A3.0 defines a discontinuity as “an interruption of the typical structure of a material, such as a lack of homogeneity in the mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.” It defines a defect as “a discontinuity or discontinuities that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. The term designates rejectability.” For the purpose of this guide, reference will be made to detection of discontinuities without regard to the distinction between acceptance or rejection.

Discontinuities may be found in the weld metal, heat-affected, and base metal zones of weldments made in the five basic weld joint types: butt, T-, corner, lap, and edge. The following subclause presents a partial list of discontinuities that may be encountered in the fabrication of metals by welding. When specific discontinuities are located in the weld metal, heat affected, or base metal zones, the abbreviations WMZ, HAZ, and BMZ, respectively, are used to indicate the location.

**4.2 List of Discontinuities.** The most common types of discontinuities in butt, T-, corner, lap, and edge joints are listed in Table 1 and depicted in Figures 1 through 10. Where the list indicates that the discontinuity is generally located in the weld, it may be expected to appear in almost any type of weld. Tungsten inclusions are an exception. Tungsten inclusions are found only in welds made by the gas tungsten arc or plasma arc welding processes.

Weld and base metal discontinuities of specific types are more common when certain welding processes and joint details are used (see Table 2). High restraint and limited access to portions of a weld joint may cause a higher than normal incidence of weld and base metal discontinuities. Each general type of discontinuity is discussed in detail in this clause.

**4.3 Porosity [see Table 1 (1)]<sup>1</sup>.** Porosity is a cavity type discontinuity formed by gas entrapment during weld solidification. The discontinuity formed is generally spherical, but it may be elongated. A common cause of porosity is contamination during welding. Generally, porosity is not considered to be as detrimental as other discontinuities, such as cracks or incomplete fusion. The rounded shape of porosity does not concentrate stress as much as sharp discontinuities like cracks or incomplete fusion. Porosity is an indication that welding parameters, welding technique, welding consumables, gas shielding, or joint fit-up are not being properly controlled for the welding process selected or that the base metal is contaminated or of a composition incompatible with the weld filler metal being used. Important information regarding the cause of the problem is provided by describing both the shape and orientation of individual pores or geometric array of adjacent pores.

An example of this utility is the distinction between elongated porosity and piping porosity. Both have lengths greater than their width, but they differ because of their orientation with respect to the weld axis. They also differ in terms of how they are caused.

By providing this additional detail, an inspector is giving more information than a standard will normally require, but it can be very helpful in determining what corrective action to take.

**4.3.1 Scattered Porosity [see Table 1 (1)(a)]** is porosity uniformly distributed throughout the weld metal. When scattered porosity is encountered, the cause is generally faulty welding techniques or materials. The joint preparation technique or materials used may also result in conditions that cause scattered porosity.

If a weld solidifies slowly enough to allow most of the gas to pass to the surface before weld solidification, there will be few pores in the weld.

**4.3.2 Cluster Porosity [see Table 1 (1)(b)]** is a localized array of porosity having a random geometric distribution. It often results from improper welding parameters, techniques, or consumables.

<sup>1</sup> The numbers in parentheses in 4.3 through 4.17 refer to numbers in Table 1 and Figures 1 through 10.

**Table 1**  
**Common Types of Discontinuities**

Type of Discontinuity	Subclause	Location	Remarks
(1) Porosity	4.3	WMZ	Porosity could also be found in the BMZ and HAZ if the base metal is a casting.
(a) Scattered	4.3.1		
(b) Cluster	4.3.2		
(c) Piping	4.3.3		
(d) Aligned	4.3.4		
(e) Elongated	4.3.5		
(2) Inclusion	4.4	WMZ, WI	
(a) Slag	4.4.1		
(b) Tungsten	4.4.2		
(3) Incomplete fusion	4.5	WMZ/WI	Fusion face or between adjoining weld beads.
(4) Incomplete joint penetration	4.6	BMZ	Weld root in a groove weld.
(5) Undercut	4.7	WI/HAZ	Adjacent to weld toe or weld root in base metal.
(6) Underfill	4.8	WMZ	Weld face or root surface of a groove weld.
(7) Overlap	4.9	WMZ	Weld toe or root surface.
(8) Lamination	4.10	BMZ	Base metal, generally near mid-thickness of section.
(9) Delamination	4.11	BMZ	Base metal, generally near mid-thickness of section.
(10) Seam and lap	4.12	BMZ	Base metal surface generally aligned with rolling direction.
(11) Lamellar tear	4.13	BMZ	Base metal.
(12) Crack (includes hot cracks and cold cracks described in text)	4.14		
	4.14.1		
(a) Longitudinal	4.14.2, 4.14.3	WMZ, HAZ, BMZ	Weld metal or base metal adjacent to WI.
(b) Transverse	4.14.2, 4.14.4	WMZ, HAZ, BMZ	Weld metal (may propagate into HAZ and base metal).
(c) Crater	4.14.5	WMZ	Weld metal at point where arc is terminated.
(d) Throat	4.14.6	WMZ	Parallel to weld axis. Through the throat of a fillet weld.
(e) Toe	4.14.7	WI, HAZ	Root surface or weld root.
(f) Face and Root	4.14.8	WMZ	Face or Root or their surfaces.
(g) Underbead / HAZ	4.14.9	HAZ	HAZ (may propagate into base metal).
(13) Concavity	4.15	WMZ	Weld face of a fillet weld.
(14) Convexity	4.16	WMZ	Weld face of a fillet weld.
(15) Weld reinforcement	4.17	WMZ	Weld face or root surface of a groove weld.
(16) Spatter		WMZ, BMZ	Weld face or base metal surface.
(17) Arc strike		WMZ, BMZ	Weld face or base metal surface.

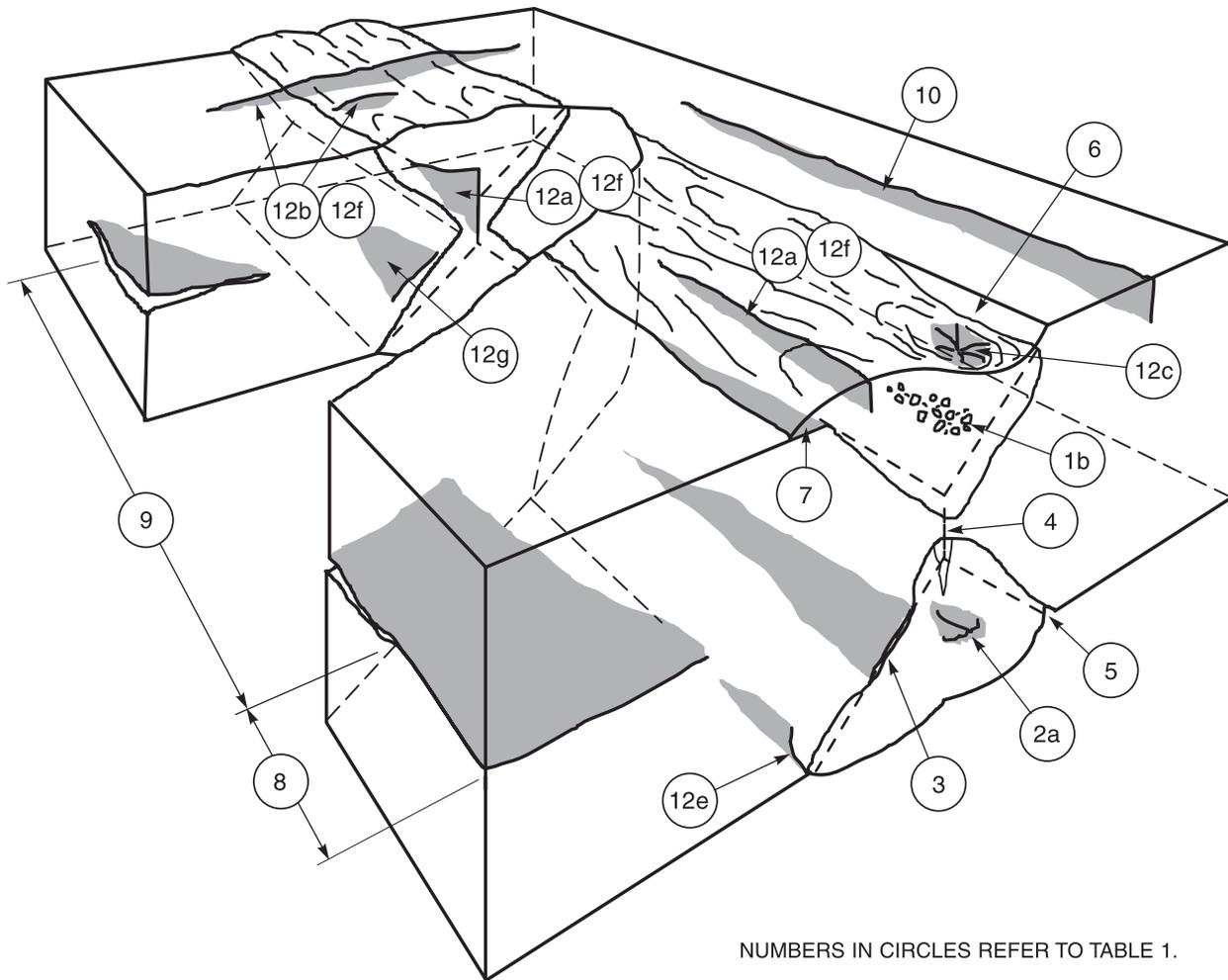
Legend:

WMZ—weld metal zone

BMZ—base metal zone

HAZ—heat-affected zone

WI—weld interface



**Figure 1—Double-V-Groove Weld in Butt Joint**

**4.3.3 Piping Porosity** [see Table 1 (1)(c)] is a form of porosity having a length greater than its width that lies approximately perpendicular to the weld face. Piping porosity may also be referred to as wormhole porosity. Piping porosity in fillet welds extends from the weld root toward the weld surface. Much of the piping porosity found in welds does not extend all the way to the surface. Careful excavation may also reveal subsurface porosity.

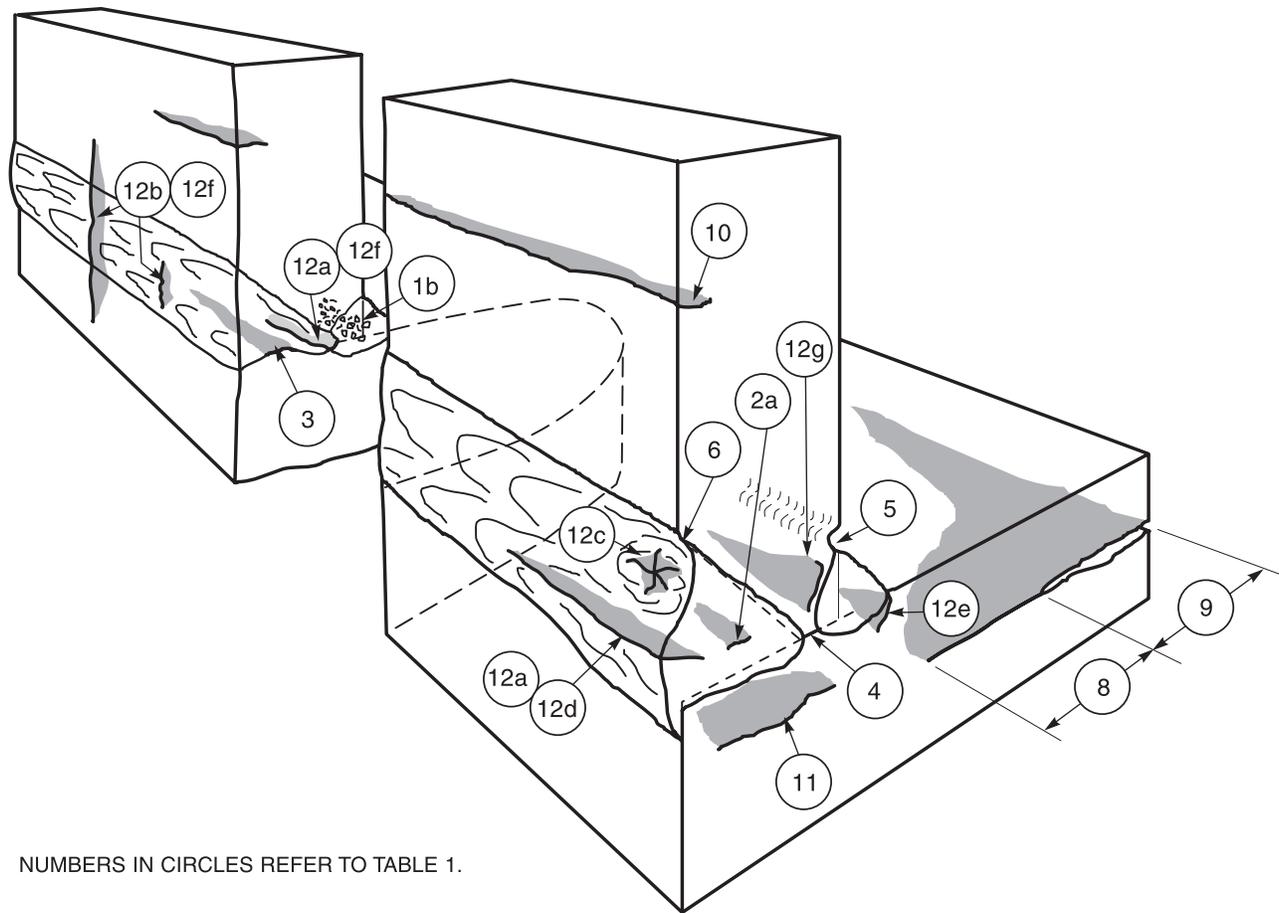
**4.3.4 Aligned Porosity** [see Table 1 (1)(d)] is a localized array of porosity oriented in a line. The pores may be spherical or elongated. It often occurs along a weld interface, the interface of weld beads, or near the weld root, and is caused by contamination that leads to gas evolution at those locations. Aligned porosity is sometimes referred to as linear porosity.

**4.3.5 Elongated Porosity** [see Table 1 (1)(e)] is a form of porosity having a length greater than its width that lies approximately parallel to the weld axis.

**4.4 Inclusions** [see Table 1 (2)] are entrapped foreign solid material, such as slag, flux, tungsten, or oxide.

**4.4.1 Slag Inclusions** [see Table 1 (2)(a)] are discontinuities resulting from the entrapment of nonmetallic products within the weld metal. Slag inclusions result from the mutual dissolution of flux and nonmetallic impurities in some welding processes.

Slag inclusions can be found in welds made with any arc welding process that employs flux as a shielding medium. In general, slag inclusions result from improper welding techniques, the lack of adequate access for welding the joint,



NUMBERS IN CIRCLES REFER TO TABLE 1.

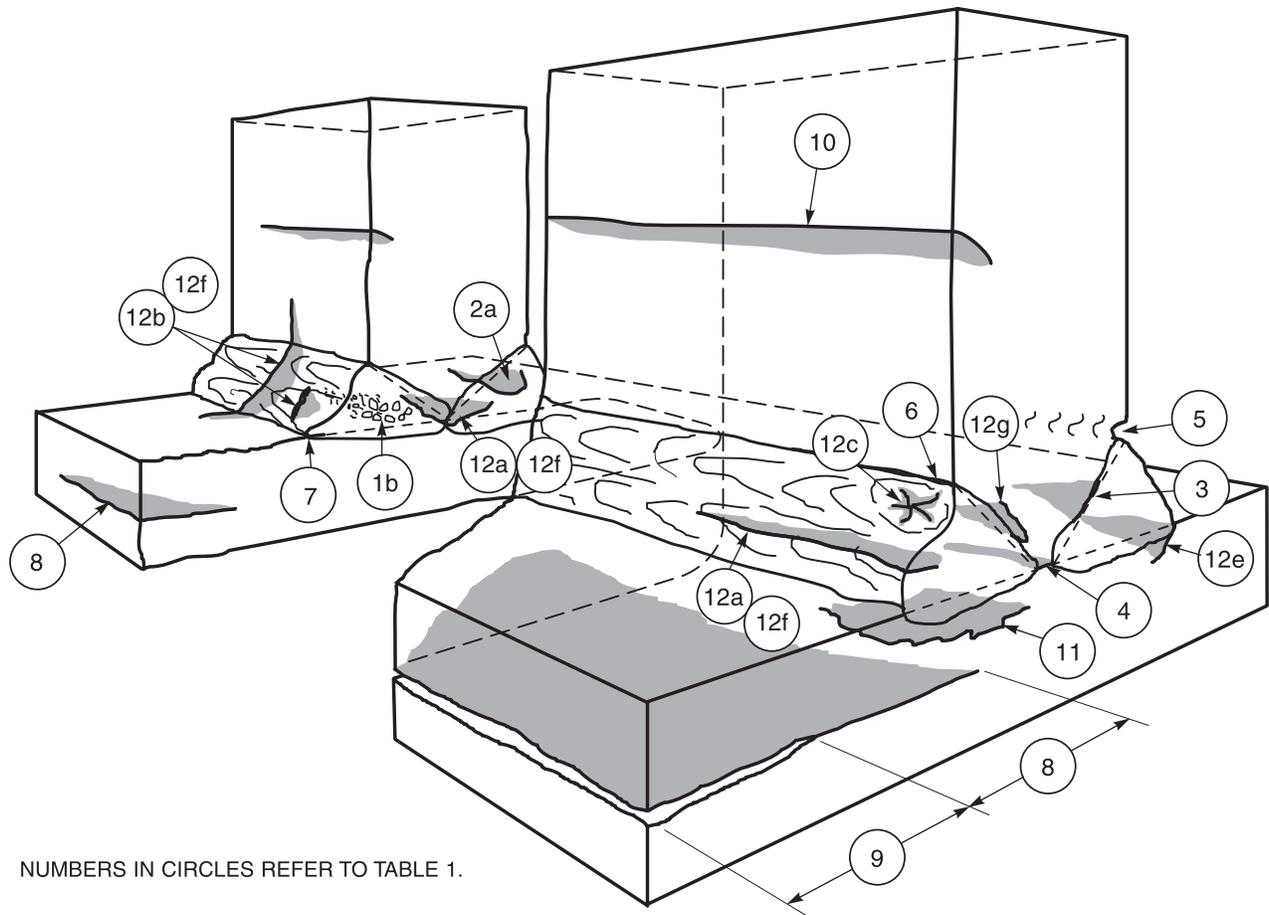
**Figure 2—Single-Bevel-Groove and Fillet Welds in Corner Joint**

or improper cleaning of the weld between passes. Due to its relatively low density and melting point, molten slag will normally flow to the surface of the weld pass. Sharp notches in the weld interface or between passes often cause slag to be entrapped under the molten weld metal. The release of slag from the molten metal will be expedited by any factor that tends to make the metal less viscous or retard its solidification, such as high heat input.

**4.4.2 Tungsten Inclusions [see Table 1 (2)(b)]** are tungsten particles trapped in weld metal. Tungsten inclusions are often associated with the gas tungsten arc welding process and are sometimes associated with the plasma arc welding process. In these processes, a nonconsumable tungsten electrode is used to establish and maintain a welding arc between the electrode and the weld or base metal. If the tungsten electrode is dipped into the molten metal, becomes contaminated or embrittled, or if the current is set too high so as to deposit tungsten droplets, tungsten inclusions may result. Tungsten inclusions appear as light indications on radiographs because tungsten is denser than steel or aluminum and attenuates more of the radiation.

**4.5 Incomplete Fusion [see Table 1 (3)]** is a weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads. It is the result of improper welding techniques, improper preparation of the base metal, or improper joint design.

**4.6 Incomplete Joint Penetration [see Table 1 (4)]** is a joint root condition in a groove weld in which weld metal does not extend through the joint thickness. The unpenetrated and unfused area is a discontinuity described as incomplete joint penetration. Incomplete joint penetration may result from insufficient welding heat, improper joint design (e.g., thickness the welding arc cannot penetrate), or improper lateral control of the welding arc.



NUMBERS IN CIRCLES REFER TO TABLE 1.

**Figure 3—Double-Bevel-Groove Weld in T-Joint**

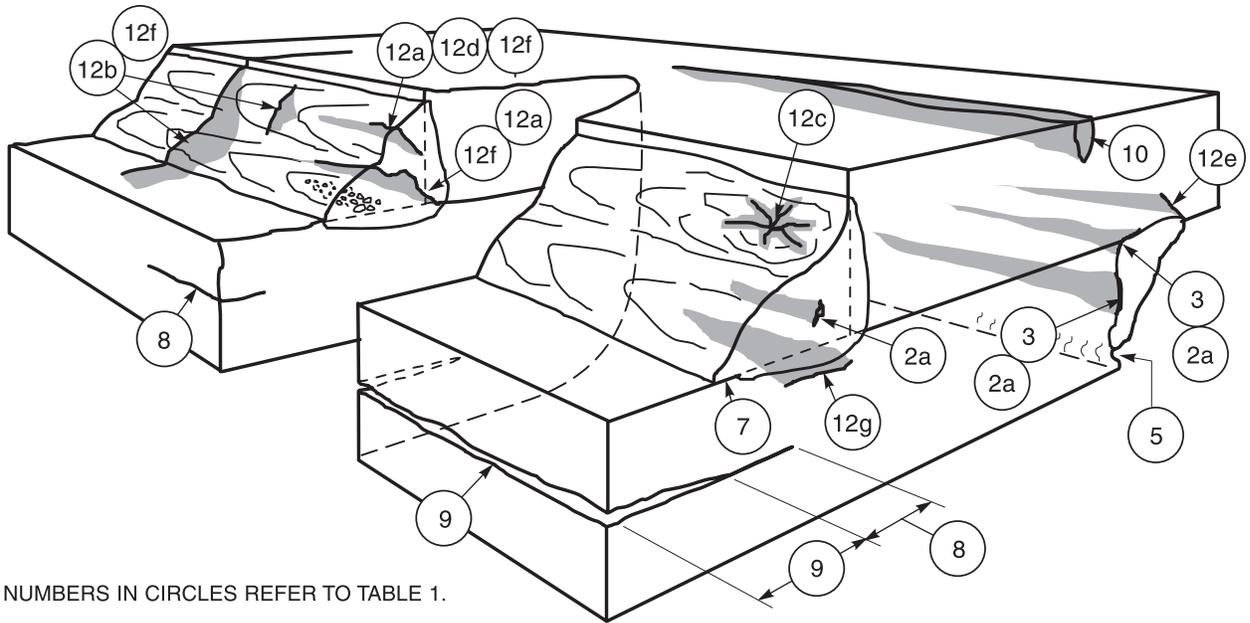
Some welding processes have much greater penetrating ability than others. For joints welded from both sides, backgouging may be specified before welding the other side to ensure that there is no incomplete joint penetration. Pipe welds are especially vulnerable to this type of discontinuity, since the inside of the pipe is usually inaccessible. Designers may employ a backing ring or consumable inserts to aid welders in such cases. Welds that are required to have complete joint penetration may require examination by visual and some other nondestructive examination method.

**4.7 Undercut** [see Table 1 (5)] is a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal. This groove creates a mechanical notch which is a stress concentrator. Undercut is generally associated with either improper welding techniques (such as excessive welding travel speed) or excessive welding currents, or both.

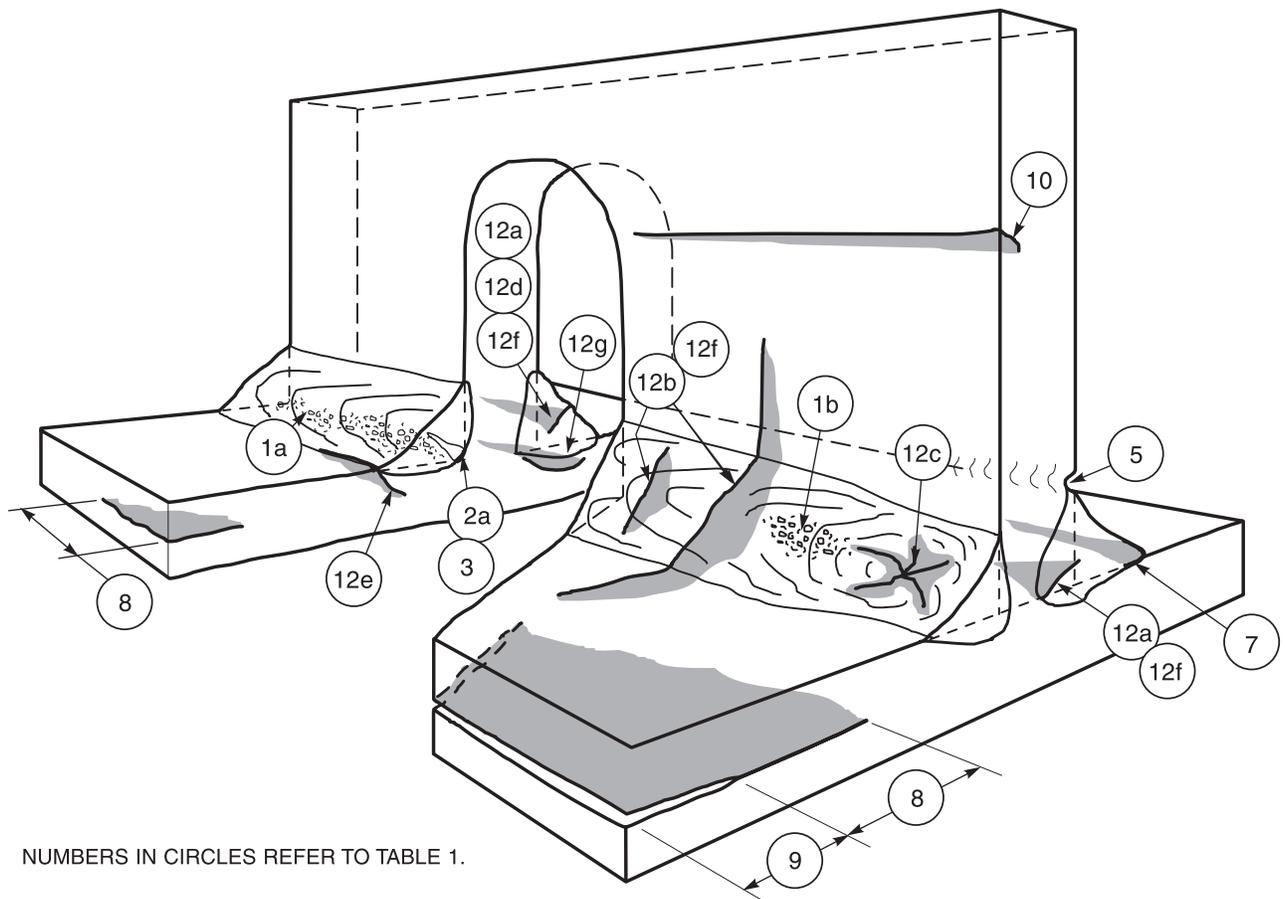
**4.8 Underfill** [see Table 1 (6)] is a condition in which the weld face or root surface of a groove weld extends below the adjacent surface of the base metal. It results from the failure of the welder to completely fill the weld joint.

**4.9 Overlap** [see Table 1 (7)] is the protrusion of unfused weld metal beyond the weld toe or weld root. Overlap is a surface discontinuity that forms a mechanical notch and is nearly always considered rejectable. Two common causes of overlap may be insufficient travel speed for the given electrical parameters and improper preparation of the base metal.

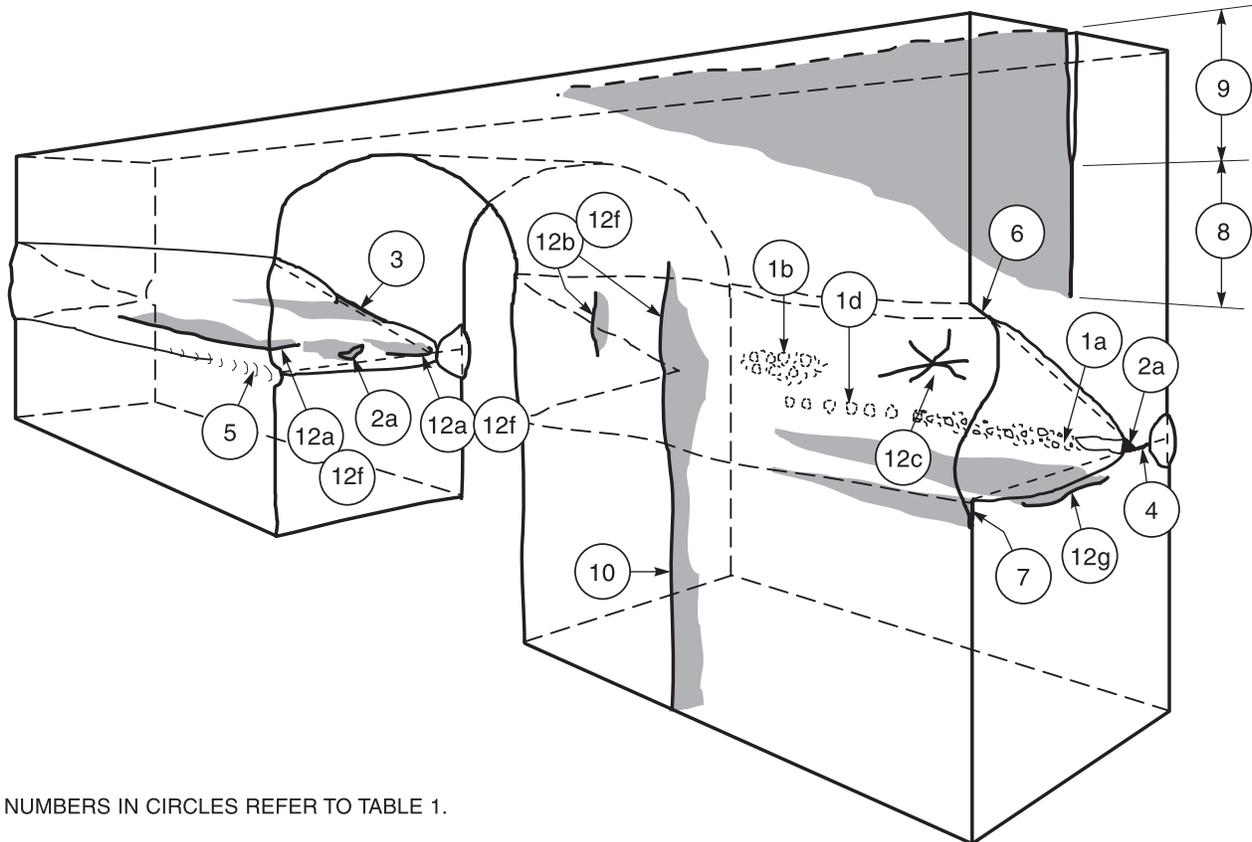
**4.10 Lamination** [see Table 1 (8)] is a type of base metal discontinuity with separation or weakness generally aligned parallel to the worked surface of a rolled product. Laminations may be completely internal and are usually detected nondestructively by ultrasonic examination. They may also extend to an edge or end, where they are visible at the surface and may be detected by visual, liquid penetrant, or magnetic particle examination. They may be found when cutting or machining exposes internal laminations.



**Figure 4—Double Fillet Weld in Lap Joint**



**Figure 5—Single Pass Double Fillet Weld in T-Joint**



NUMBERS IN CIRCLES REFER TO TABLE 1.

**Figure 6—Single-Bevel-Groove Weld in Butt Joint**

Laminations are formed when gas voids, shrinkage cavities, or nonmetallic inclusions in the original ingot are rolled flat. They generally run parallel to the surface of rolled products and are most commonly found in shapes and plates. Metals containing laminations cannot be relied upon to carry tensile stress in the through-thickness direction.

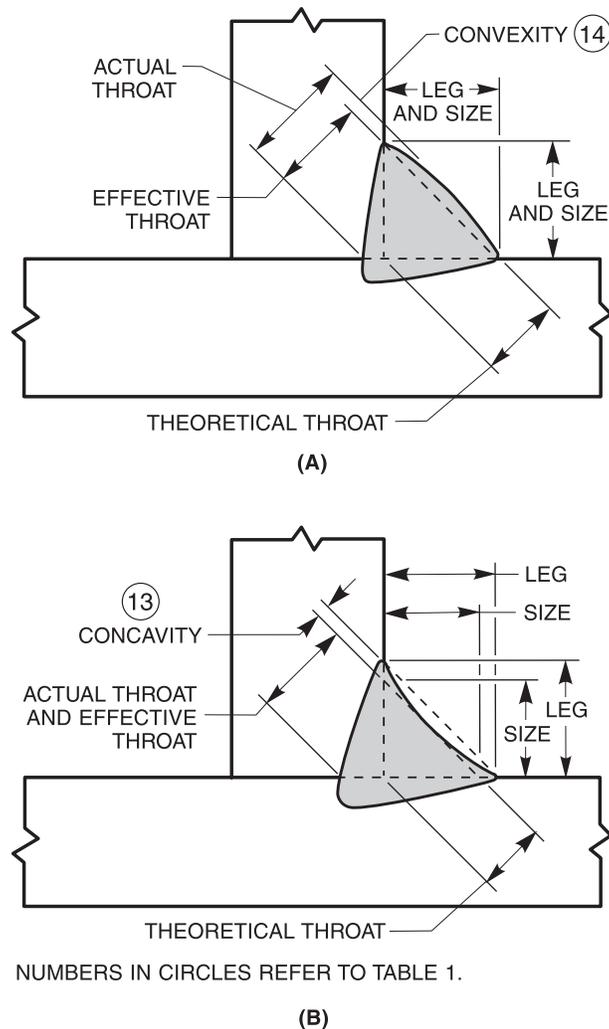
**4.11 Delamination [see Table 1 (9)]** is a lamination that has separated under stress.

**4.12 Seams or Laps [see Table 1 (10)]** are base metal discontinuities that may be found in rolled, drawn, and forged products. They differ from laminations in that they appear on the surface of the worked product. When the discontinuity is parallel to the principal stress, it is not generally a critical defect. When seams and laps are perpendicular to the applied or residual stresses, they will often propagate as cracks. While seams and laps are surface discontinuities, their presence may be masked by manufacturing processes that have subsequently modified the surface of the mill product. Welding over seams and laps can cause cracking or porosity.

**4.13 Lamellar Tear [see Table 1 (11)]** is a subsurface terraced and step-like crack in the base metal with a basic orientation parallel to the wrought surface. It is caused by tensile stresses in the through-thickness direction of base metals weakened by the presence of small, dispersed, planar shaped, nonmetallic inclusions which are parallel to the metal surface. Lamellar tearing most often occurs in heavy section materials.

Lamellar tearing may extend over long distances and generally initiates in regions of the base metal that have a high incidence of stringer-like, nonmetallic inclusions in parallel planes and high residual stress. The fracture usually propagates from one lamellar plane to another by shear along lines that are near normal to the rolled surface.

**4.14 Cracks [see Table 1 (12)]** are defined as fracture type discontinuities characterized by a sharp tip and high ratio of length and width to opening displacement. They can occur in the weld metal zone, heat-affected zone, and base metal when localized stresses exceed the ultimate strength of the material. Cracking often initiates at stress concentrations caused by



**Figure 7—Fillet Weld Terminology**

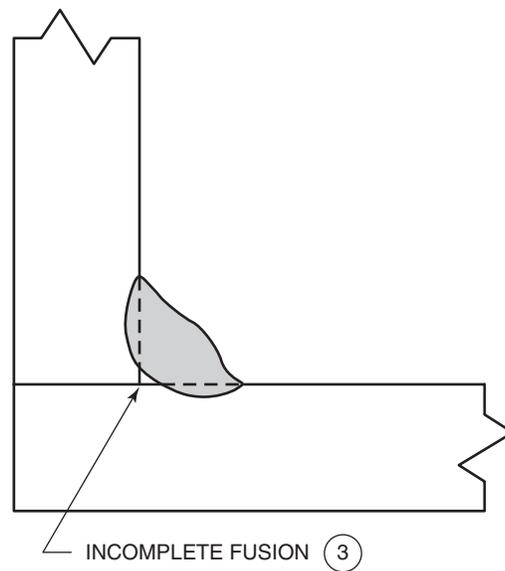
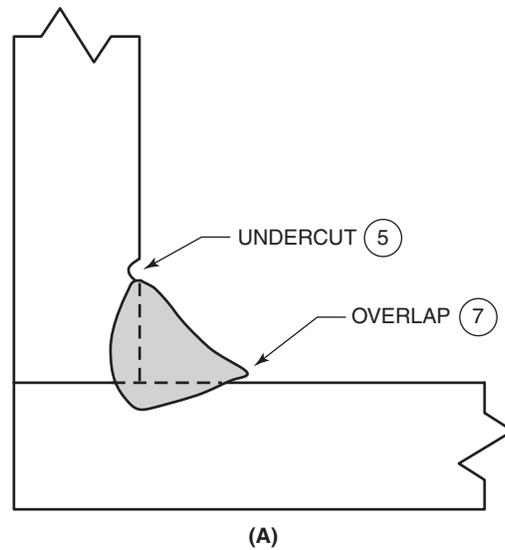
other discontinuities or near mechanical notches associated with the weldment design. Stresses that cause cracking may be either residual or service induced. Residual stresses may pre-exist in base metals or be fabrication induced.

A crack formed in a layer of a weld and not completely removed before the next layer is deposited tends to progress into the layer above and then each succeeding layer until finally it may appear at the surface. The final extension to the surface may occur during cooling after welding has been completed.

**4.14.1 Crack Types.** Cracks can generally be classified as either hot cracks or cold cracks. Hot cracks occur in a metal during solidification or at elevated temperatures. Hot cracks can occur in both heat-affected (HAZ) and weld metal zones (WMZ) and are the result of insufficient ductility at high temperature. Hot cracks propagate between grains (intergranular) in the weld metal zone or at the weld interface.

Cold cracks occur in a metal at or near ambient temperatures. Cold cracks can occur in base metal (BMZ), heat-affected (HAZ), and weld metal zones (WMZ). They may result from improper welding practices or service conditions. Cold cracks propagate both between grains (intergranular) and through grains (transgranular).

**4.14.2 Crack Orientation.** Cracks may be described as either longitudinal or transverse, depending on their orientation (see Figure 11). When a crack is parallel to the weld axis it is called a longitudinal crack regardless of its location in the weld, weld interface, or base metal zones. Similarly, transverse cracks are perpendicular to the axis of the weld. These may be limited in size and contained completely within a particular zone, or they may propagate further into adjacent zones.



NUMBERS IN CIRCLES REFER TO TABLE 1.

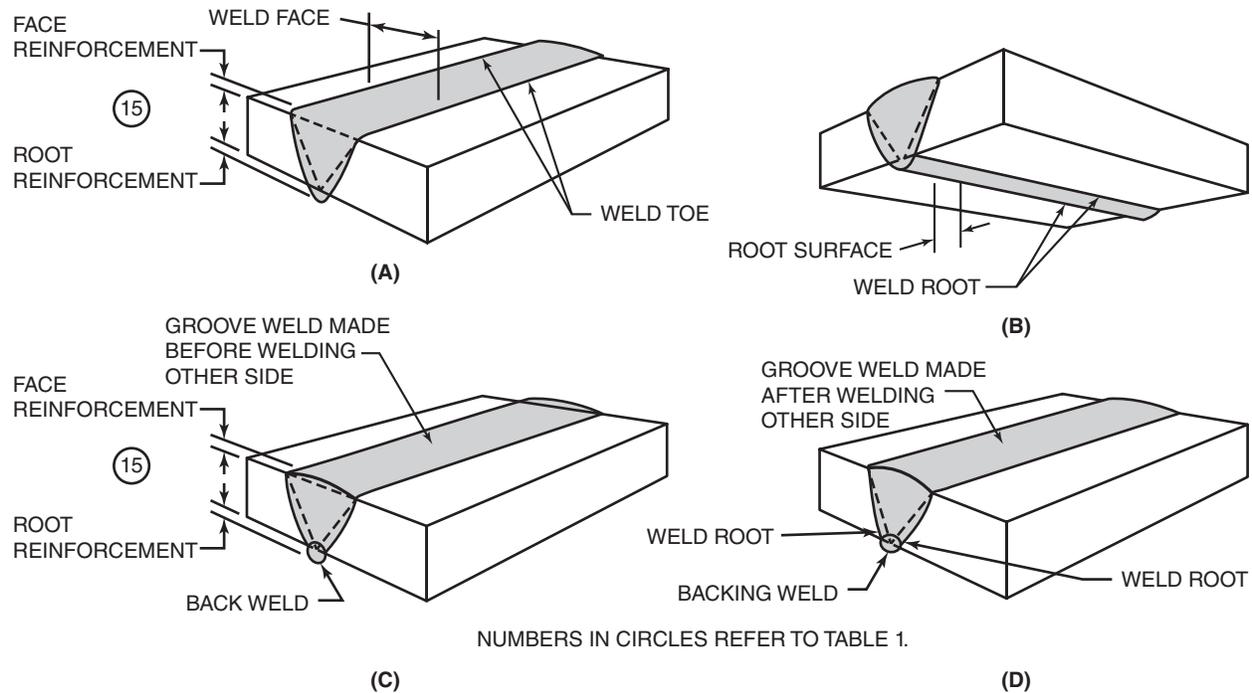
(B)

**Figure 8—Fillet Weld Discontinuities**

**4.14.3 Longitudinal Cracks [see Table 1 (12)(a)].** Longitudinal cracks in small welds between heavy sections are often the result of high cooling rates and high restraint. In submerged arc welding they are commonly associated with high welding speeds or may be related to porosity problems that do not appear at the surface of the weld.

**4.14.4 Transverse Cracks [see Table 1 (12)(b)]** are the result of stresses created by the longitudinal shrinkage of the weld metal combined with residual stresses in the base metal, high joint restraint, and/or weld metal with excessive levels of hydrogen for the strength of the deposited weld metal.

**4.14.5 Crater Cracks [see Table 1 (12)(c)]** occur in the crater of a weld when the weld is improperly terminated. They are sometimes referred to as star cracks, though they may have other configurations. Crater cracks are hot cracks



**Figure 9—Groove Weld Terminology**

usually forming a pronged star-like network. Crater cracks are found most frequently in materials with high coefficients of thermal expansion, for example austenitic stainless steel and aluminum. However, the occurrence of any such cracks can be minimized or prevented by filling the crater to a slightly convex shape prior to terminating the arc.

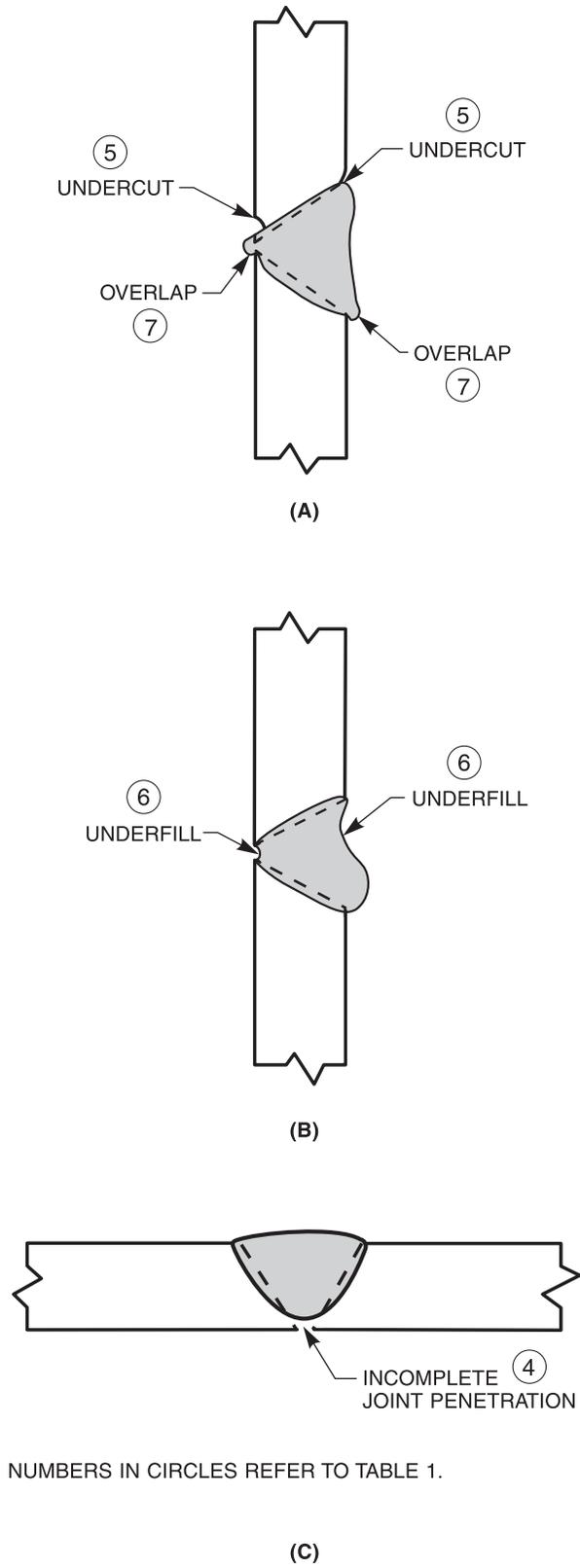
**4.14.6 Throat Cracks** [see Table 1 (12)(d)] are longitudinal cracks oriented along the throat of fillet welds. They are generally, but not always, hot cracks.

**4.14.7 Toe Cracks** [see Table 1 (12)(e)] are generally cold cracks. They initiate and propagate from the weld toe where shrinkage stresses are concentrated. Toe cracks initiate approximately normal to the base metal surface. These cracks are generally the result of thermal shrinkage stresses acting on a weld heat-affected zone. Some toe cracks occur because the transverse tensile properties of the base metal cannot accommodate the shrinkage stresses that are imposed by welding.

**4.14.8 Face and Root Cracks** [see Table 1 (12)(f)] are cracks at the weld face or root or in their surfaces.

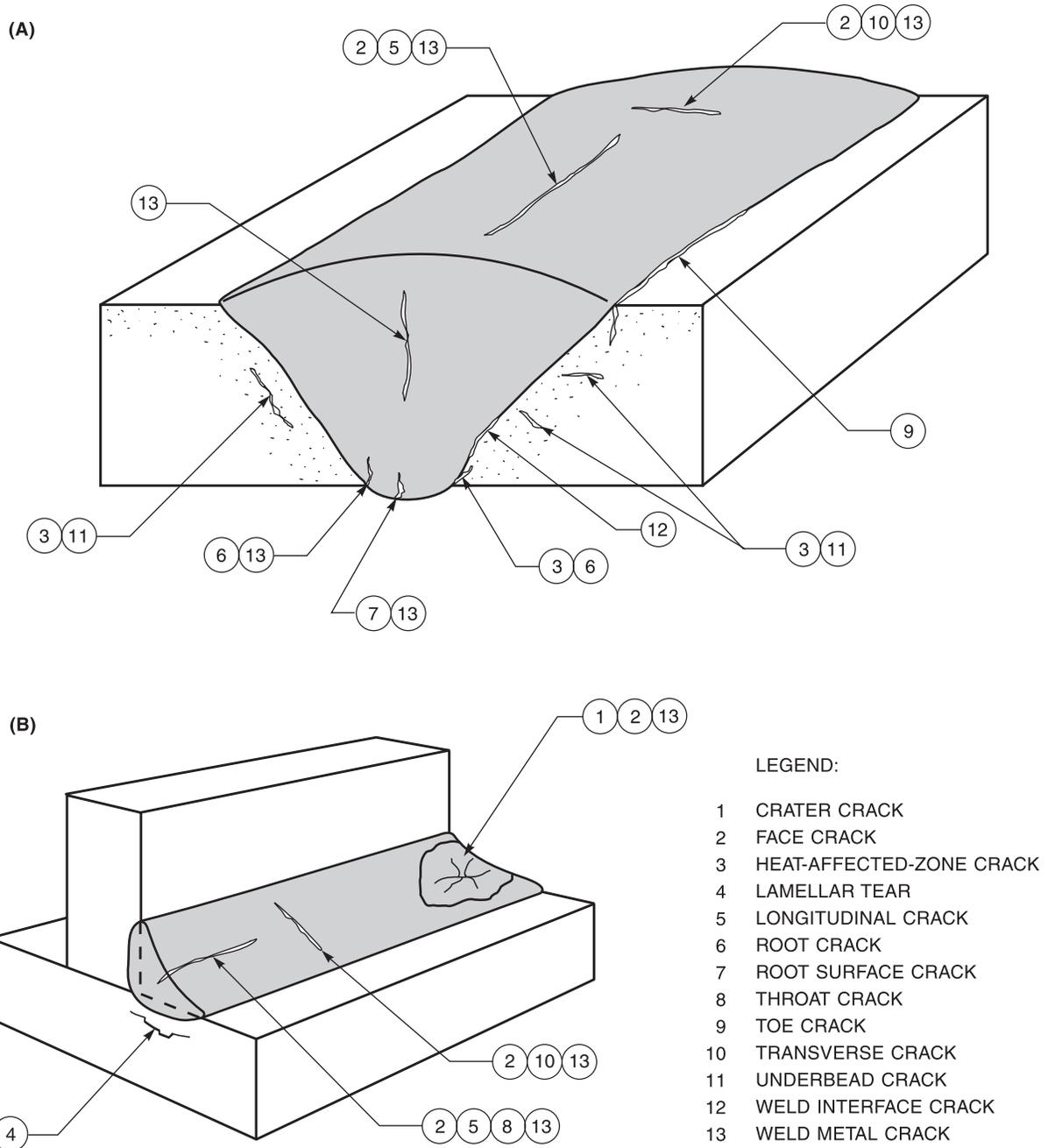
**4.14.9 Underbead / Heat-Affected Zone Cracks** [see Table 1 (12)(g)] are generally cold cracks that form in the heat-affected zone of the base metal. They are generally short, but several may join to form a continuous crack. Underbead and HAZ cracks in steel alloys are often associated with the presence of diffusible hydrogen introduced during the process of welding, a microstructure of relatively low ductility, and high residual stress. They are found at regular intervals under the weld and also outline boundaries in the heat-affected zone, where residual welding stresses are highest.

**4.15 Concavity** [see Table 1 (13)] is the maximum distance from the face of a concave fillet weld to a line joining the weld toes. Excessive concavity is sometimes called insufficient throat. Concavity is not rejectable unless it creates an undersize weld that exceeds the limits of the applicable code. Concave fillet welds must be inspected by using a fillet weld gauge capable of measuring the throat dimension, since that is the limiting dimension in terms of the size of a concave fillet weld. A concave profile fillet weld size cannot be correctly measured by the leg size.



NUMBERS IN CIRCLES REFER TO TABLE 1.

**Figure 10—Groove Weld Discontinuities**



**Figure 11—Crack Types**

**4.16 Convexity [see Table 1 (14)].** Convexity is the maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes. Convexity is not rejectable unless it exceeds the limits of the applicable code. The convexity results in a mechanical notch at the junction of the weld face and the base metal similar to that produced by overlap. The severity is greater when the convexity is greater.

**4.17 Weld Reinforcement [see Table 1 (15)].** In groove welds, weld reinforcement is weld metal in excess of the quantity required to fill a joint. Weld reinforcement may be located at either the root or face of a groove weld. Weld reinforcement is undesirable when it creates high stress concentrations at the weld toes or weld root similar to convexity. When weld reinforcement is excessive, it tends to create stress concentrations due to a sharp transition between the weld and base material at the weld toe. This condition may result from improper welding technique or insufficient welding current.

**Table 2**  
**Discontinuities Commonly Encountered with Welding Processes**

Welding Process	Porosity	Slag	Incomplete Fusion	Incomplete Joint Penetration	Undercut	Overlap	Cracks
<b>Arc</b>							
SW—Stud welding	X		X		X		X
PAW—Plasma arc welding	X		X	X	X		X
SAW—Submerged arc welding	X	X	X	X	X	X	X
GTAW—Gas arc tungsten welding	X		X	X	X		X
EGW—Electrogas welding	X		X	X	X	X	X
GMAW—Gas metal arc welding	X		X	X	X	X	X
FCAW—Flux cored arc welding	X	X	X	X	X	X	X
SMAW—Shielded metal arc welding	X	X	X	X	X	X	X
CAW—Carbon arc welding	X	X	X	X	X	X	X
<b>Resistance</b>							
RSW—Resistance spot welding	X <sub>a</sub>		X	X			X
RSEW—Resistance seam welding	X <sub>a</sub>		X	X			X
PW—Projection welding			X	X			X
FW—Flash welding			X	X			
UW—Upset welding			X	X			
<b>Oxyfuel Gas</b>							
OAW—Oxyacetylene welding	X		X	X	X	X	X
OHW—Oxyhydrogen welding	X		X	X	X	X	X
PGW—Pressure gas welding	X		X				X
<b>Solid-State<sup>b</sup></b>							
CW—Cold welding		X					X
DFW—Diffusion welding		X					X
EXW—Explosion welding		X					
FOW—Forge welding		X					
FRW—Friction welding		X					
USW—Ultrasonic welding		X					
<b>Other</b>							
EBW—Electron beam welding	X		X	X			X
ESW—Electroslag welding	X	X	X		X	X	X
IW—Induction welding			X				X
LBW—Laser beam welding	X		X	X			X
PEW—Percussion welding			X				X
TW—Thermite welding	X	X	X				X

<sup>a</sup> Porosity in resistance welds is more properly called voids.

<sup>b</sup> Solid-state is not a fusion process, so incomplete joining is incomplete welding rather than incomplete fusion.

## 5. Nondestructive Examination Methods

Nondestructive examination (NDE) is a general term used in this guide to identify all methods that permit evaluation of welds and adjacent areas without destroying their usefulness. The purpose of this clause is to acquaint the reader with some of the more commonly used nondestructive examination methods and the fundamental conditions for their use. Visual examination is the most common of all nondestructive examinations.

For the purpose of this guide the following basic NDE methods will be discussed:

- (1) Visual
- (2) Liquid Penetrant
- (3) Magnetic Particle
- (4) Radiographic
- (5) Ultrasonic
- (6) Electromagnetic (Eddy Current)
- (7) Leak

The salient features of each method are summarized in tables in Annex A. It should be noted that nondestructive examination does not eliminate the need for destructive testing, but rather complements it. It is not uncommon for the acceptance-rejection criteria for nondestructive examination to be developed by destructive testing investigations correlated with NDE results. The general knowledge presented in this guide should be of valuable assistance to the reader as it provides an overview of the examination methods without unnecessary detail.

**5.1 Visual (VT).** The integrity of most welds is verified principally by visual examination. Even for weldments with joints specified for examination throughout by other nondestructive examination methods, visual examination still constitutes an important part of practical quality control. Therefore, visual examination is of the first order of importance. Many codes and other standards require welds to be accepted by visual examination prior to the performance of any other nondestructive examinations. The most extensively used of any method of nondestructive examination, visual examination is easy to apply, quick, and often requires no special equipment other than good eyesight and some relatively simple and inexpensive tools. An extensive review of visual examination is contained in AWS B1.11M/B1.11, *Guide for the Visual Inspection of Welds*.

Despite the many advantages of visual examination, a major disadvantage is the need for an experienced inspector who has considerable experience and knowledge in many different areas which encompass visual welding examination. The inspector must be familiar with materials, drawings, codes, specifications, weld procedures, performance qualification, procedure qualification requirements, workmanship standards, and all other aspects of good practice in shop and field. Some codes and specifications require that the welding inspector be certified by examination in order to demonstrate that the inspector is qualified by training and experience.

Various measuring tools are used for checking the dimensions of the welds. There are many different types of fillet weld gauges used throughout the world to determine the size of fillet welds. Other gauges can be used to verify root opening, weld reinforcement, and weld bevel angle. Measuring devices are used to check root openings, clearance dimensions of backing materials and alignment and fit-up of the workpieces. Temperature indicators verify preheat and interpass temperature. Borescopes, video scopes, flashlights, and mirrors are used in areas of limited accessibility. Flexible fiberoptic examination systems enable the inspector to perform remote visual examination of some areas that are not accessible for direct visual examination or to rigid borescopes.

**5.1.1 Visual Examination and Verification Activities Prior to Welding.** Material examination prior to fabrication can eliminate conditions that tend to cause weld defects. Scabs, seams, and scale may be detected at this time, and plate laminations may be observed on cut edges. Other areas that should be inspected prior to welding are:

- (1) Verification of correct materials by check of records
- (2) Verification of a properly supported welding procedure specification (WPS)
- (3) Verification of personnel performance qualification
- (4) Verification of specified edge preparation, dimensions, and finish

- (5) Verification of alignment and fit-up of workpieces
- (6) Verification of clearance dimensions of backing strips, backing rings, and consumable inserts
- (7) Verification of cleanliness and condition of tack welds
- (8) Verification of proper preheat, when required
- (9) Verification and proper storage of welding consumables.

**5.1.2 Visual Examination and Verification Activities During Welding.** Visual examination continues during the fabrication process. Various items that should be checked are the following:

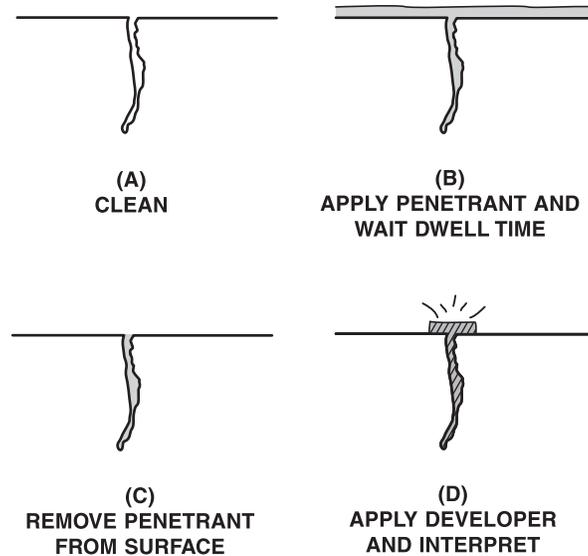
- (1) Welding process and site conditions
- (2) Welding variables and their conformance with welding procedures
- (3) Filler metal
- (4) Flux and protective gases
- (5) Preheat and interpass temperatures
- (6) Weld sequencing for distortion control
- (7) Preparation of 1st side weld root before welding 2nd side
- (8) Interpass chipping, grinding, or gouging
- (9) Examination intervals (either time or sequence)
- (10) Proper condition of welding equipment and location of welding leads.

**5.1.3 Visual Examination and Verification Activities After Welding.** If all preliminary aspects of the inspection program have been performed properly, VT after welding should be little more than a verification that all preceding steps have been successful. Some items which should be included are:

- (1) Dimensional accuracy of the completed weldment
- (2) Completion of welding
- (3) Size of welds
- (4) Contour, reinforcement, and surface finish of welds
- (5) Degree of underfill, undercut, and overlap
- (6) Weld spatter, crater cracks, impression marking, scratches, gouges, and arc strikes
- (7) Handling damage
- (8) Completion of postweld heat treatment
- (9) Nondestructive examinations and results
- (10) Preparation and maintenance of inspection records

Visual examination performed before, during, and after welding is capable of detecting many discontinuities at minimum cost and permits timely correction of those discontinuities. Correction of welding discontinuities during fabrication minimizes their impact on delivery of the finished part. Without in-process visual examination, additional NDE may be required after welding to locate and identify the same discontinuities. Weld repair after fabrication is complete will only add costs and schedule delays to the project. All inspections and the results should be documented by the inspector.

**5.2 Liquid Penetrant (PT).** Liquid penetrant examination is a sensitive method of detecting and locating discontinuities, provided the discontinuities are clean and open to the surface. The method employs a penetrating liquid dye which is applied to the properly cleaned surface to be examined and which enters the discontinuity by capillary action. After a suitable dwell time, the excess penetrant is carefully removed from the surface and the part is dried. A developer is then applied which acts as a blotter, drawing the penetrant out of the discontinuity. The penetrant, drawn from an opening on the surface, indicates the presence and location of a discontinuity. The four basic steps are illustrated in Figure 12.



**Figure 12—Steps in Penetrant Testing**

There are two basic classifications of the penetrant method, both using a similar principle. One uses a visible dye and the other uses a fluorescent dye that is only visible while exposed to ultraviolet light. Visible penetrant is usually red in color to provide a contrast against the white developer background. Normal white light is usually sufficient to view any indications present.

Fluorescent penetrants produce a brilliant yellow-green indication against a dark background when viewed in a darkened area under a black (ultraviolet) light source. The fluorescent method is more sensitive than the visible dye method. Penetrants glow under ultraviolet light, making indications readily apparent to the technician. Manufacturers adjust sensitivity by adding fluorescent particles and brighteners into increasingly tenacious penetrants that resist overcleaning.

There are three different types of penetrants used with both the visible and fluorescent methods classified by how they are removed from the test surface. These are solvent removable, water washable, and post-emulsifiable.

Solvent removable penetrants are formulated to be removed with a solvent using a hand-wiping technique. They are very portable and often used for on-site examinations.

Water washable penetrants contain emulsifiers that make the oil-based penetrants soluble in water. This method requires a source of water, a means of disposing of the rinse, and some means for drying the article.

Post-emulsifiable penetrants are not water soluble. Post-emulsifiable penetrants are formulated such that a separate emulsifier must be used. The use of this emulsifier enables clean water to then be used to rinse the emulsified excess penetrant from the surface of the test piece. Post-emulsifiable penetrants are used when detection of very minute or wide, shallow discontinuities is desired.

Penetrant examination is widely applicable on ferromagnetic and nonmagnetic materials, but it is particularly useful on nonmagnetic materials such as aluminum, magnesium, and austenitic stainless steel where magnetic particle examination cannot be used. It is also useful for locating cracks or other discontinuities which may cause leaks in containers and pipes.

An interesting example of liquid penetrant testing is filling or brushing the inside of a container with penetrant and checking the outside for leaks (see 5.7). This procedure detects some through-wall discontinuities.

Liquid penetrant examination is relatively inexpensive. The process is simple and operators find little difficulty in learning to apply it properly. The success of liquid penetrant examination methods depends on the experience and visual acuity of the inspector. In addition, the examination should be performed in accordance with a written procedure. It should be pointed out that some substances in penetrants can have a deleterious effect on either welds or base metals and can affect the service life of the weld or application of the product. Penetrants are difficult to remove completely from discontinuities, and if corrosive to the material, or otherwise not compatible with the product application, they should be avoided.

There are two common methods of recording a PT indication for evaluation. A photograph may be taken of indications produced by the examination. Another method involves the application of clear plastic tape over the indication. When the tape is lifted off the test surface, the indication will adhere to the tape and may be transferred to the examination report for future reference.

**5.3 Magnetic Particle (MT).** This NDE method is used for locating surface or near surface discontinuities in ferromagnetic materials. Magnetic particle examination is based on the principle that magnetic lines of force will be distorted by a change in material continuity; i.e., a discontinuity creating a magnetic field or flux leakage (see Figure 13).

A weldment can be magnetized by passing an electric current through the weld area (direct magnetization) or by placing the weldment in a magnetic field (indirect magnetization). The electric current creates a magnetic field perpendicular to the current flow. For this reason, magnetic fields are applied in at least two directions, perpendicular to each other, to assure the examination areas are completely evaluated.

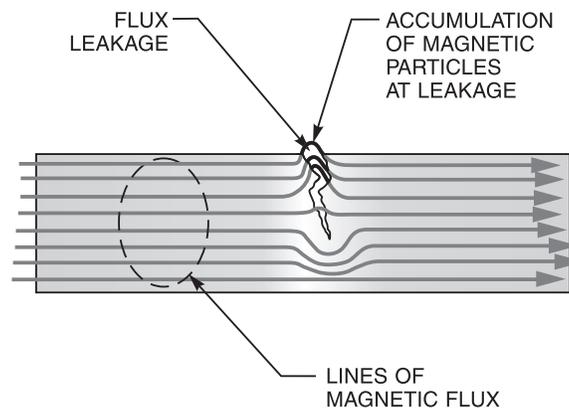
The direct magnetization method is normally used with direct current (dc), half wave direct current (hwdc) or full wave direct current (fwdc) (see Figure 14). These types of currents have penetrating abilities that generally enable slightly subsurface discontinuities to be detected. Direct magnetization may also be used with alternating current (ac), which is limited to the detection of surface discontinuities only. Alternating current is also the method of choice for the location of service related fatigue discontinuities.

Detection of slightly subsurface discontinuities depends on several variables, including the magnetizing method, the type of current, the directions and density of the magnetic flux, and the material properties of the weldment. When evaluating surface discontinuities only, alternating current (ac) is preferred with the indirect magnetization method (see Figure 15).

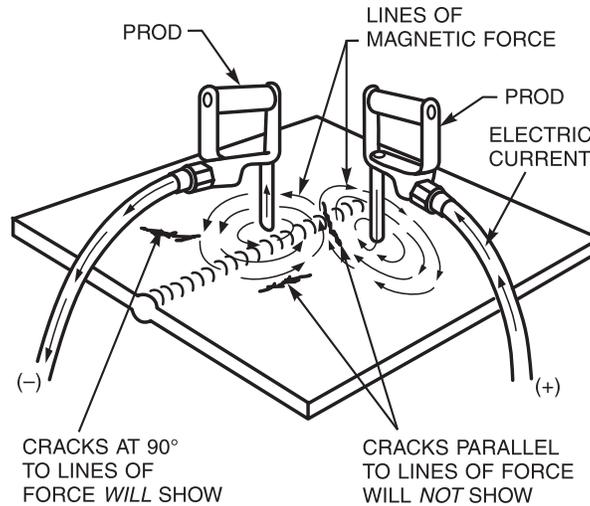
The alternating current continuously reverses the polarity (direction) of the magnetic field and causes the magnetic particles to have greater mobility than is possible with direct current. Particle mobility promotes the detection of weak flux leakages produced by small surface breaking discontinuities. However, alternating current has a very low penetrating ability because the alternating magnetic field is concentrated at the surface of the metal.

When the magnetic field has been established within the workpiece, magnetic particles (examination medium) are applied to the surface to be examined. The magnetic particles can be dry or suspended in a liquid. Discontinuities can be further enhanced using fluorescent magnetic particles and observing them under black light. After removal of excess particles, the magnetic flux leakage field at a detectable discontinuity reveals its location, shape, and size. These indications usually are distinguishable by their appearance as sharp, well defined lines of medium against the background of the part being inspected.

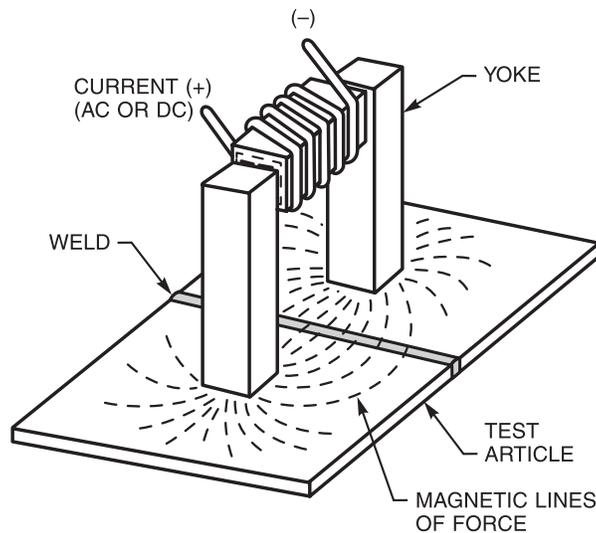
Magnetic particle examination can be very beneficial as an in-process evaluation technique. Assurance of a sound weld before the weld is completed may prevent costly repairs of the final product. In-process magnetic particle examination has become more of a common practice due to the portability of modern lightweight equipment. This advantage aids in reducing production time. Examples of in-process magnetic particle examinations are of backgouged welds and repair excavations to ensure discontinuity removal.



**Figure 13—Magnetic Field Leakage**



**Figure 14—Direct Magnetization Using dc Prods**



**Figure 15—Indirect Magnetization Using a Yoke**

Magnetic particle examination is less expensive than radiographic (RT) or ultrasonic (UT) examination. The equipment needed to perform magnetic particle examination is less expensive than the equipment used for radiographic or ultrasonic examinations. The training and experience needed to perform magnetic particle examinations is less extensive than required to perform radiography and ultrasonic examinations. Using MT, the inspector obtains an instant visible indication of the size and orientation of the discontinuity. Compared to PT, the MT method has the advantage of revealing discontinuities that are not open to the surface, and therefore not detectable by PT. Magnetic particle examination is generally faster, requires less surface preparation, and is therefore usually more economical than liquid penetrant examination (neglecting equipment costs).

The MT method is limited to ferromagnetic materials. Welded joints between metals of dissimilar magnetic characteristics may create nonrelevant magnetic particle indications even though the welds themselves are sound. Most weld surfaces

are acceptable for magnetic particle examination after the removal of slag, or other extraneous material which may mechanically hold the test medium or block the medium from a true discontinuity. Surface preparation requirements prior to MT are generally addressed in the requirements of the applicable code.

The most common methods for recording an MT indication are the same as those described in subclause 5.2 for the recording of a PT indication.

**5.4 Radiographic (RT).** RT is a method of nondestructive examination that utilizes ionizing radiation to penetrate an object and reveal information about its internal conditions. When the test object is exposed to ionizing radiation some of the radiation is attenuated, some of it is scattered, and some passes through the object. The ionizing radiation passing through the test object is detected by a detector. (see Figure 16). Most radiographic techniques used today employ radiographic film that records a latent image when exposed to ionizing radiation. Other detectors, such as imaging plates, are also used and new radiographic imaging technologies are being developed.

The basic process of radiographic examination involves three general steps:

- (1) Set up and control of the exposure
- (2) Development or processing of the image recording medium
- (3) Interpret and evaluate the developed image

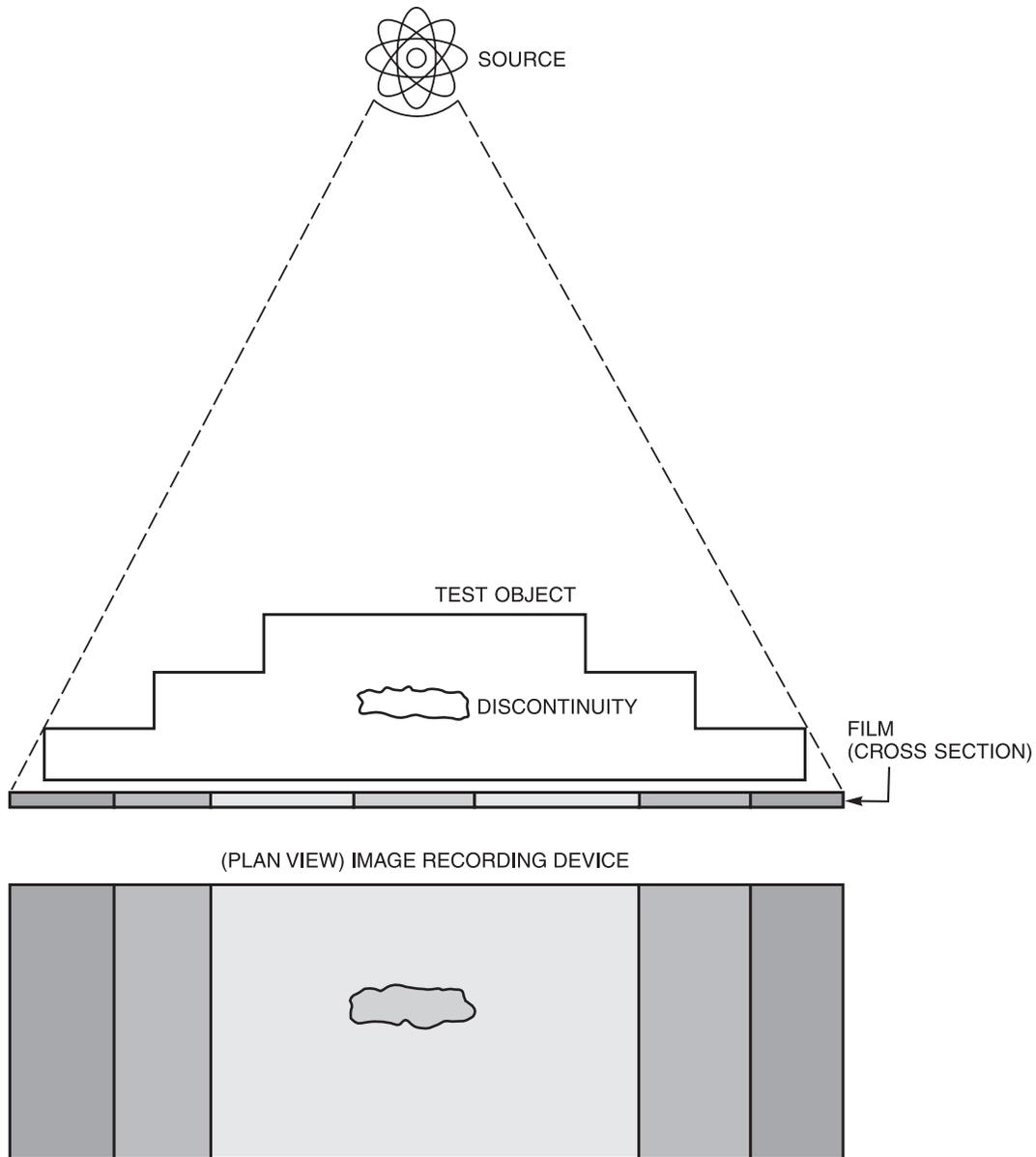
The essential elements needed to carry out these three operations consist of:

- (1) A source of radiation
- (2) Object to be radiographed
- (3) Object identification markers, station markers and image quality indicators (IQI)
- (4) Some type of recording medium (i.e. radiographic film or digital detector)
- (5) A skilled person capable of producing a radiograph
- (6) A means of chemically processing the exposed film or a video/computer system to assimilate the image data
- (7) Skilled person capable of interpreting and evaluating the radiographic images
- (8) Storage and archival capabilities

The two types of radiation sources commonly used in radiographic examination are X-ray machines and radioactive isotopes. X-radiation is produced by machines which range from portable, low energy units capable of radiographing relatively thin objects, to mammoth linear accelerators and betatrons capable of radiographing steel materials up to 500 mm [20 in] thick. Gamma radiation is emitted by radioisotopes, the two most common used for radiography purposes being Cobalt 60 and Iridium 192. Cobalt 60 will effectively penetrate up to approximately 200 mm [8 in] of steel; whereas, Iridium 192 is effectively limited to a steel thickness of about 75 mm [3 in].

The radiographic process is dependent upon varying amounts of radiation being absorbed by the different areas of the object material. Two key factors determine the rates of differential absorption: the amount of mass represented by the material and the penetrating power (defined by the energy) of the radiation source. The amount of mass is related to the thickness and the density or composition of the material. The penetrating power of the radiation source is dependent on the instrument settings of the X-ray machine or the characteristic energy level and intensity of the particular isotope selected for gamma radiography. The differences in absorption occurring during the exposure process account for the dark and light regions on the radiographic image. The basic radiographic exposure principles apply to each of the recording media used in the radiographic method whether film or digital capture.

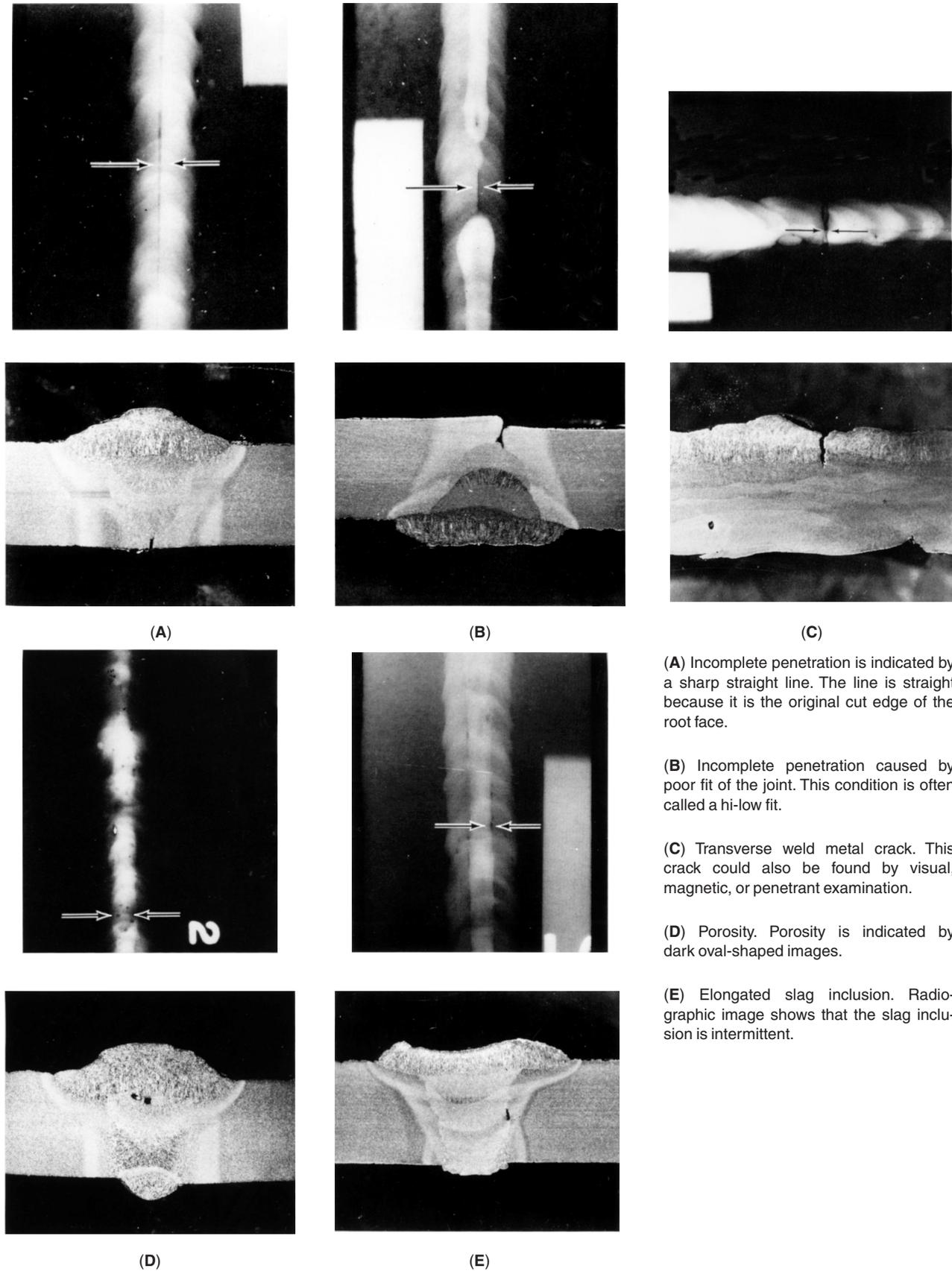
Film, still the most commonly used capture medium, consists of a thin plastic base coated with fine crystals of silver bromide (emulsion). The grain size of the silver bromide emulsion determines speed and sensitivity of the film. The emulsion is sensitive to radiation just as photographic film is to light, leaving a latent image on the film. Developing (chemical processing) the film converts this latent image produced on the film emulsion by exposure to radiation into a visible, permanent image. The development procedure is a critical part of the process that may affect the quality of the film and image along with the archival life of the film. Following the film and chemical manufacturer's recommendations is very important for quality and life of the film.



**Figure 16—Making a Radiograph**

Whereas traditional radiography uses film as the imaging medium, other techniques, such as radioscopy or real time radiography, use a fluorescent screen to convert radiation to light for direct viewing or electronic imaging. Light from the fluorescent screens may be viewed directly by the human eye, amplified in an image intensifier tube with video output, or imaged directly by a low-light level camera.

Digitization of these analog signals of radioscopy is a technique of digital imaging. Digital radiographic imaging differs from radioscopy in that the systems are not video-based. Rather, digital systems use discrete sensors with the data from each detection pixel being read out into a file structure to form the pixels of the digital image file. Computer based systems are the primary focus of these techniques allowing for manipulation of the data to provide a variety of image controls. Computed Tomography is such a system, which is a powerful digital data reconstruction technique for radiographic information. By using digital imagery and collecting multiple data sets at different projection views from the source, the data may be reconstructed digitally to create a series of focused planes through the object providing for a 3D type presentation of the data.



(A) Incomplete penetration is indicated by a sharp straight line. The line is straight because it is the original cut edge of the root face.

(B) Incomplete penetration caused by poor fit of the joint. This condition is often called a hi-low fit.

(C) Transverse weld metal crack. This crack could also be found by visual, magnetic, or penetrant examination.

(D) Porosity. Porosity is indicated by dark oval-shaped images.

(E) Elongated slag inclusion. Radiographic image shows that the slag inclusion is intermittent.

**Figure 17—Radiographs of Weld Discontinuities and Macrosections**

The interpretation of a radiograph involves identifying the images resulting from the various light and dark regions on the recording medium. For example, on a film radiograph the dark regions represent the more easily penetrated parts of the material (i.e., thin sections and most discontinuities) while the lighter regions represent the more difficult areas to penetrate (i.e., thick sections). Interpretation, for film radiography, is usually performed in a room with subdued background lighting by placing the radiograph in front of a relatively bright light source. The subdued background lighting reduces light reflections off the film surface which may obscure the interpreter's view of radiographic images. With digital images the radiographs will be viewed on a computer monitor, and therefore back lighting may not be a factor in the interpreter's review of the images. These computer-type systems provide for several controls which the interpreter may use for the evaluation of the image which are not found for film radiography.

Figure 17 illustrates several types of weld discontinuities an interpreter may encounter in the evaluation of radiographs of welds. Figure 18 provides examples of digitally captured radiographic images.

A significant limitation of radiography is that discontinuities must be favorably aligned with the radiation beam to be reliably detected. This is usually not a problem for discontinuities such as porosity (generally round in cross section) or slag inclusions (generally round or irregular in cross section) because they align with the beam from any direction.

This is not the case with planar discontinuities such as cracks, incomplete fusion and laminations. A substantial portion of these discontinuities must be favorably aligned with the radiation beam to be reliably detected by the interpreter. Figure 19 illustrates this limitation. Some digital radiographic techniques, due to the automation of the process, may allow for better alignment during operations, providing for adequate imagery of such discontinuities, but the basic principle above still applies.

Radiography also has several other limitations:

- (1) It presents a potential radiation hazard to both the RT personnel performing operations and to the general public.
- (2) The cost of radiographic equipment, facilities, safety programs, and related licensing is relatively high.
- (3) There is usually a relatively long time, compared to other methods, between the exposure process and the availability of results for film radiography, due to the chemical development required. The digital techniques may provide faster results with just a matter of minutes from exposure to a radiographic image being displayed.
- (4) Accessibility to both sides of the work piece is required to set up exposure equipment and the imaging apparatus.

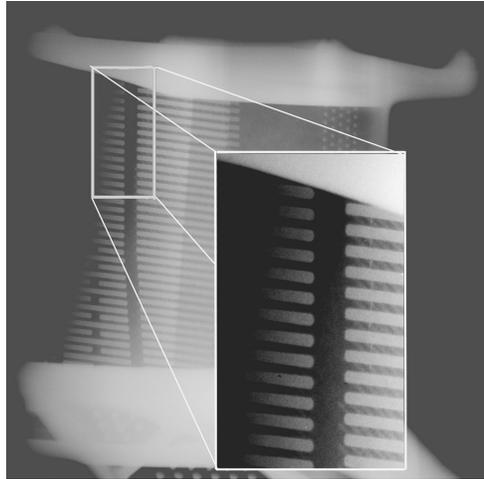
Compared to other nondestructive examination methods, radiography has the following advantages:

- (1) It is generally not restricted by the type of material.
- (2) Both the surface and sub-surface discontinuities may be detected.
- (3) Radiographic images aid in the characterization (identification) of discontinuities.
- (4) It provides a permanent record for future review.
- (5) The radiograph may be used to make a map, or transparent overlay, in order to locate the exact defect orientation and assist in the removal of the unacceptable condition in the material under examination.

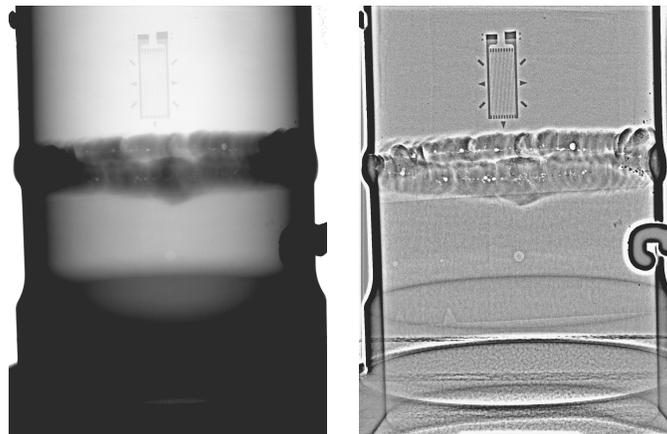
**5.5 Ultrasonic (UT).** Ultrasonic examination (UT) is one of the most widely used methods of nondestructive examination. Its primary application is the detection and characterization of internal discontinuities. It is also used to detect surface discontinuities, to define bond characteristics, and to measure thickness. The pulse-echo method with A-scan data presentation is most commonly used for examining welds. This system utilizes a cathode ray tube (CRT) or digital screen to display examination information. The basic components of the pulse-echo method are shown in block diagram form in Figure 20.

High-frequency sound waves are introduced into the material to detect surface and subsurface discontinuities. The sound waves travel through the material with some loss of energy (attenuation) and are reflected at interfaces. The reflected sound beam is detected and analyzed to define the presence and location of discontinuities.

In many respects, a beam of ultrasound is similar to a beam of light; both are waves and obey a general wave equation. Each travels at a characteristic velocity in a given homogeneous medium. The velocity in a given medium depends on the properties of the medium and the vibrational movement of the wave. Like beams of light, ultrasonic beams are reflected from surfaces (see Figure 21); refracted when they cross a boundary between two substances that have different



Courtesy VJ Technologies, East Haven, CT



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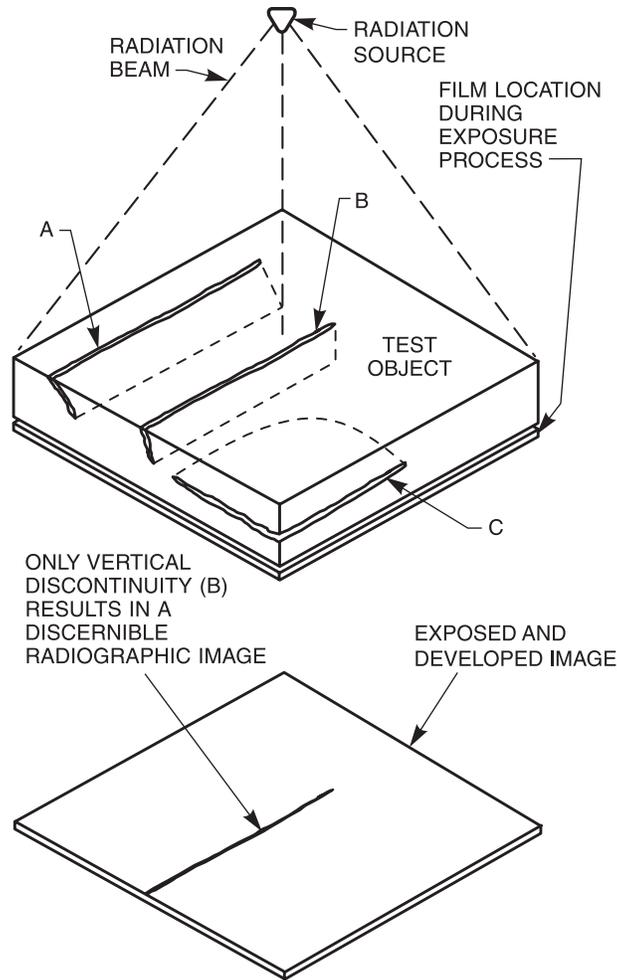
### Figure 18—Examples of Digitally Captured Radiographic Images

characteristic sound velocities (see Figure 22); and diffracted at edges or around obstacles (see Figure 23). Scattering by rough surfaces, particles, or coarse grains reduces the energy of an ultrasonic beam, similar to the manner in which scattering reduces the intensity of a light beam.

Ultrasonic examination is usually performed with either longitudinal waves and/or shear waves. The most commonly used frequencies are between 1 MHz and 5 MHz, with sound beams at angles of  $0^\circ$ ,  $45^\circ$ ,  $60^\circ$ , and  $70^\circ$  measured from a line perpendicular to the material surface.

In longitudinal beam testing (commonly used to examine plate material), sound in the form of ultrasonic vibrations is introduced into the part perpendicular (normal) to the entry surface by a straight beam search unit (see Figure 24 for an example of a back reflection on a 200 mm [8 in] thick part using a 250 mm [10 in] screen range, and also an example of a mid-wall discontinuity indication). When the entry surface and the back surface are parallel, a back reflection will appear on the display screen. A discontinuity lying between the front and back surfaces will also be displayed on the display screen. By measuring the height of the reflection on the display screen, from a real or artificial discontinuity of a known size, a reference level can be established such that reflections from discontinuities of unknown sizes may be evaluated.

The angle beam technique (see Figure 25) is used for the examination of welds. Ideally, only discontinuities should appear on the display screen during angle beam examination (see Figure 26). This is not always the case, however, since the



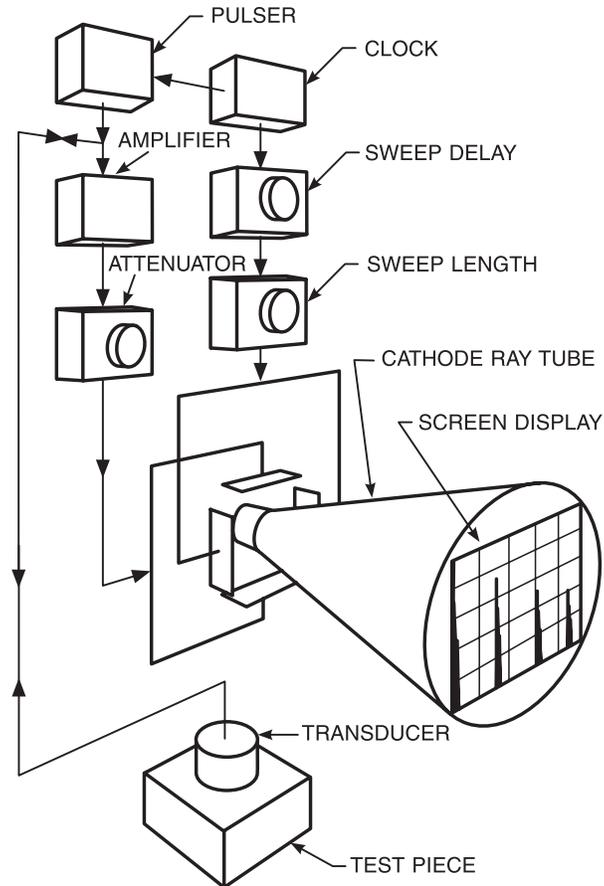
**Figure 19—Detection of Planar Discontinuities at Various Orientations by Radiography**

geometrical boundaries of the part being examined often reflect sound in the same manner as a discontinuity. Therefore, care must be taken during ultrasonic examination of joints with complex geometries (such as welds with backing bars) to assure that indications are the result of the presence of discontinuities and not simply due to the configuration of the joint. Figure 27 illustrates a true discontinuity (slag inclusion) masked by a false indication from the backing bar; however, this discontinuity can be evaluated by examining from the opposite side of the weld if accessible.

It is generally desirable to have the sound beam intercept the plane of the discontinuity at or near  $90^\circ$  so that the maximum amount of sound is reflected to the transducer. However, cracks that are not oriented perpendicular to the ultrasonic beam can be detected because their surfaces are not smooth and sound is reflected from the facets that are approximately perpendicular to the beam. The selection of the test surface for scanning with the search unit depends on accessibility. Scanning surface selection is also based on the weld shape and structure.

The scan pattern must be sufficient to pass the projected sound beam through the entire volume of weld and heat-affected zone to permit detection of possible discontinuities. This accounts for the wide variety of angle search units available. In special cases, search units are made to specific nonstandard angles.

Since it is important to intercept the discontinuity at or near  $90^\circ$ , it is common for more than one angle search unit to be used to examine a particular weld. For example, AWS D1.1/D1.1M, *Structural Welding Code—Steel*, specifies angles to be used for particular thickness and joint configurations and in some cases more than one angle is required.



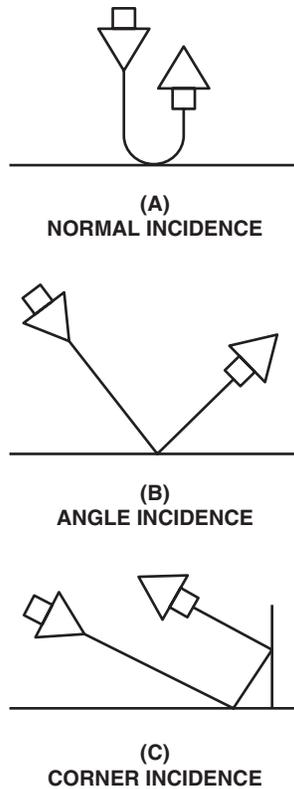
**Figure 20—Block Diagram, Pulse-Echo Flaw Detector**

The principal advantages of ultrasonic examination, as compared to other methods of nondestructive examination of metal parts are:

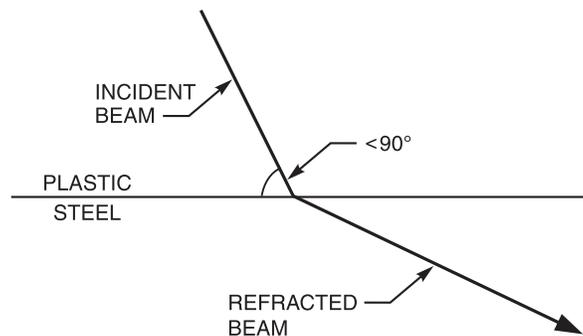
- (1) Allows the detection of discontinuities deep in the part.
- (2) High sensitivity permits the detection of very small discontinuities.
- (3) Greater accuracy in determining the position of internal discontinuities, estimating size, and characterizing the orientation, shape, and nature.
- (4) Only one surface need be accessible.
- (5) Provides almost instantaneous indications of discontinuities. This makes the method suitable for immediate interpretation, automation, rapid scanning, production line monitoring, and process control. With some systems, a permanent record of examination results can be made for future reference.
- (6) Scanning ability enables examination of a volume of metal extending from front to back surface of a weld.

Some disadvantages of ultrasonic examination include:

- (1) Requires careful attention by experienced technicians.
- (2) Extensive technical knowledge is required for the development of examination procedures and the interpretation of indications.

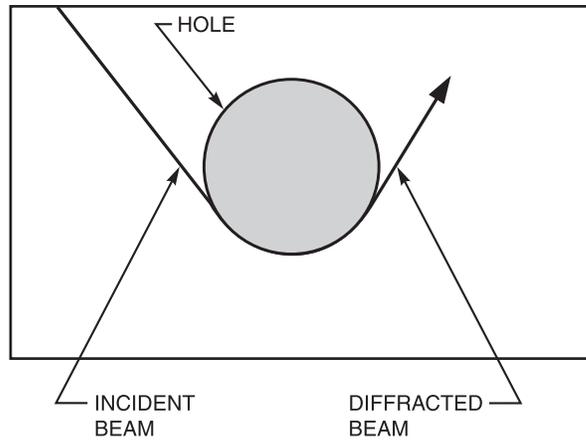


**Figure 21—Similarities Between Reflections of Light and Sound at Boundaries**

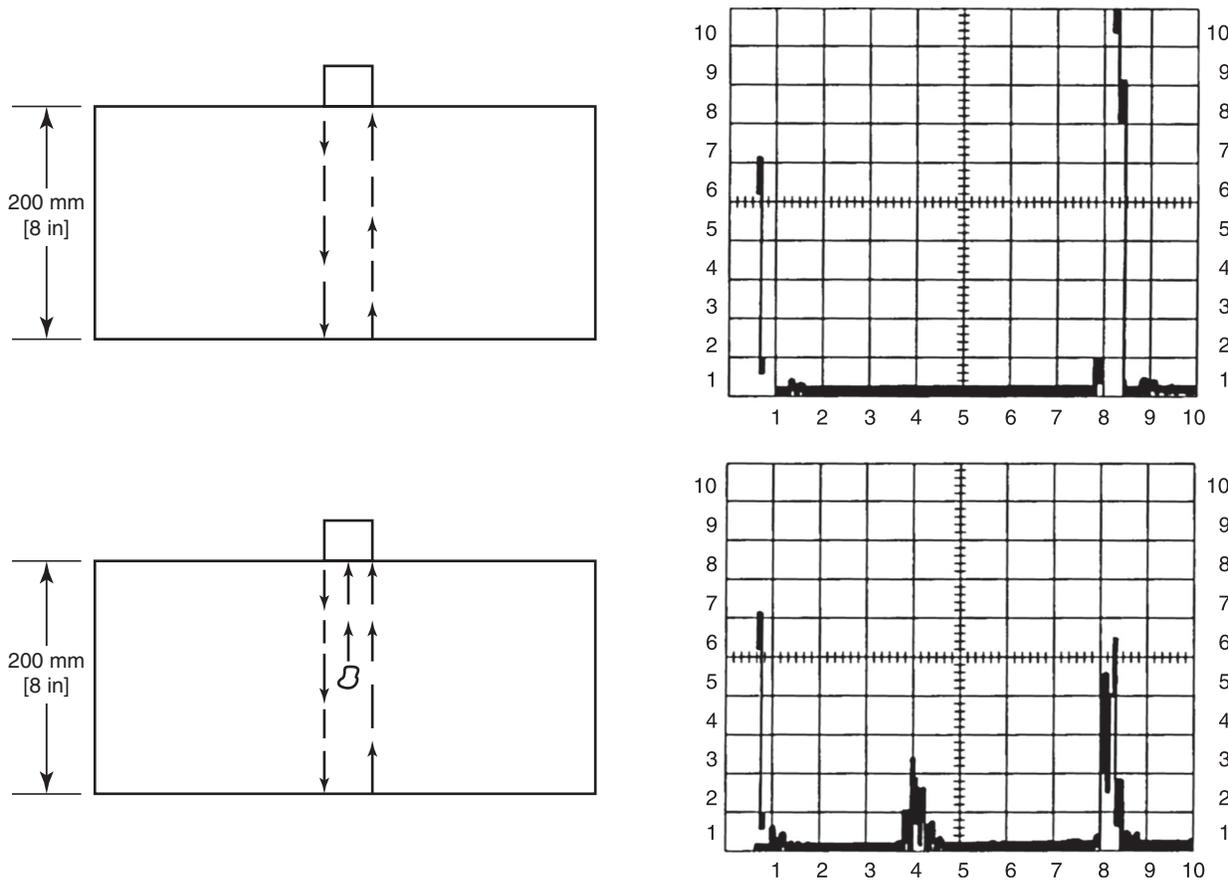


**Figure 22—Refraction**

- (3) Parts that are rough, irregular in shape, very small or thin, or inhomogeneous are difficult to examine.
- (4) Discontinuities that are present in a shallow layer immediately beneath the examination surface may not be detectable.
- (5) Couplants are needed to provide effective transfer of ultrasonic-wave energy between search units and the part being examined.
- (6) Reference standards which duplicate the exact examination conditions may be needed for calibrating the equipment.
- (7) Materials with coarse grain structures are difficult to examine.

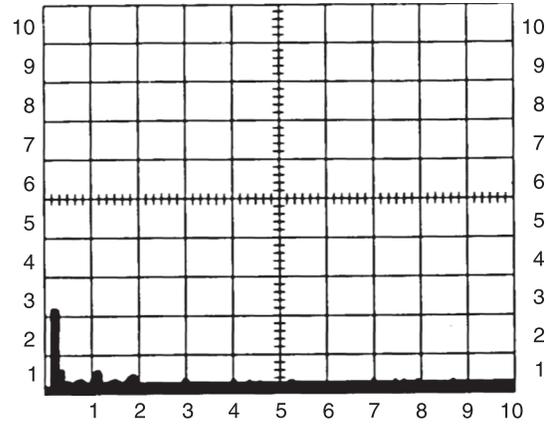
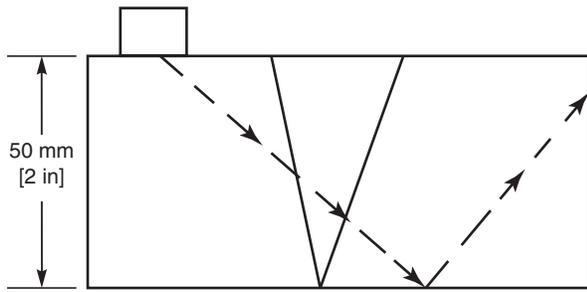


**Figure 23—Diffraction**



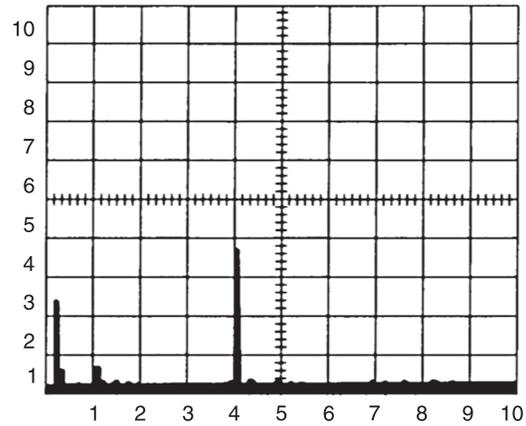
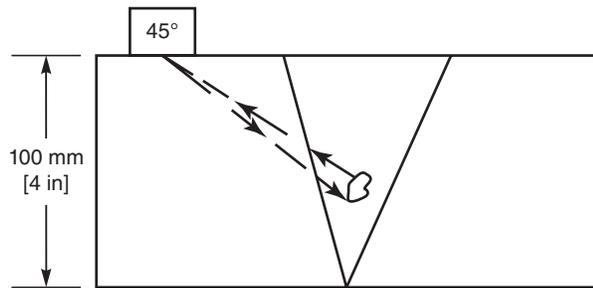
Note: Using a 250 mm [10 in] Screen Range, back reflection from 200 mm [8 in] thick part and mid-wall discontinuity indication.

**Figure 24—Example of Longitudinal Testing**



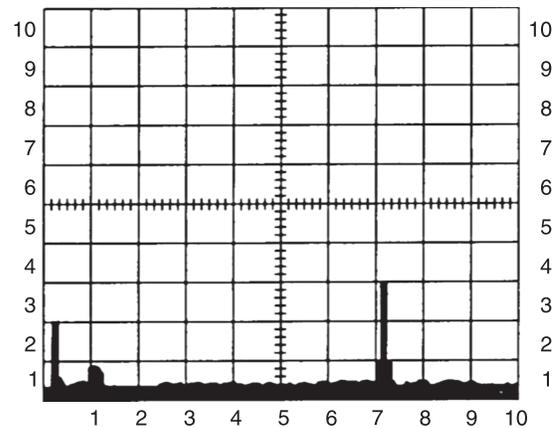
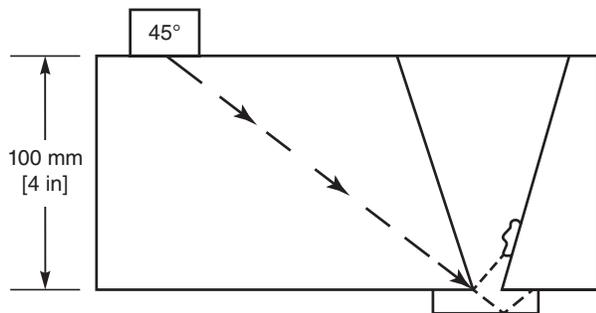
Note: Example of Angle Beam Testing - A part with no discontinuities.

**Figure 25—No Discontinuities**



Note: Example of Angle Beam Testing - A part with a discontinuity indication displayed.

**Figure 26—Discontinuity**



Note: Example of Angle Beam Testing - A part with a slag inclusion masked by a false indication from a backing bar.

**Figure 27—Backing Bar False Indication**

**5.5.1 Phased Array Ultrasonic Testing (PAUT)** PAUT is used for sizing, imaging, and flaw detection in much the same manner as standard ultrasonic methods. This technique is in use mainly in the piping, vessel and tank industries. Specific techniques and codes are still being developed for the use of PAUT in the structural and bridge industries. PAUT is commonly used to supplement, or is performed in lieu of, radiographic or traditional contact ultrasonic inspection.

A phased array instrument is a multichannel instrument used with multiple-element probes. A probe is made up of several piezoelectric elements individually controlled so that the signals they transmit or receive may be treated separately or combined as desired. The elements can be pulsed individually, simultaneously, or in a certain pattern relative to each other to create the desired beam angles or scan pattern. PAUT has the capability to produce numerous inspection angles, choices of scanning modes (generally an S-scan or an E-scan) and the ability to view or present the examination data collected in several formats or views.

S-scan (beam movement) is also called a sector scan, sectorial scan, swept angle scan, or azimuthal scan. The S-scan beam movement is a set of focal laws that provides a fan-like series of beams through a defined range of angles using the same set of elements. See Figures 28 and 29.

E-Scan, also called an electronic scan or linear scan, is a single focal law multiplexed across a grouping of active elements for a single beam angle which is stepped along the phased array probe length in defined incremental steps. See Figure 30.

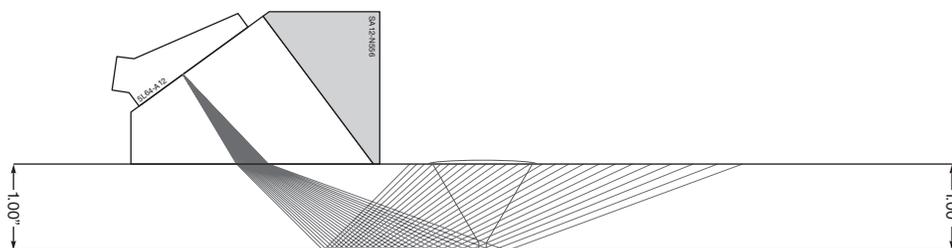
The term “linear scan” has two meanings in PAUT, however. One refers to the E-Scan and the other refers to the Line Scan. Line Scan is a scanning technique in which an E-scan, S-scan or combination thereof is performed with the beams directed perpendicular to the weld and at a fixed distance from the weld, in a manner that will provide full weld coverage.

All welds in butt joints examined by PAUT should be typically tested from each side of the weld axis where access is possible. Welds in corner and T-joints should be primarily tested from one side of the weld axis only. All welds should be tested using applicable line scans or scanning patterns that will permit the detection of both longitudinal and transverse discontinuities.

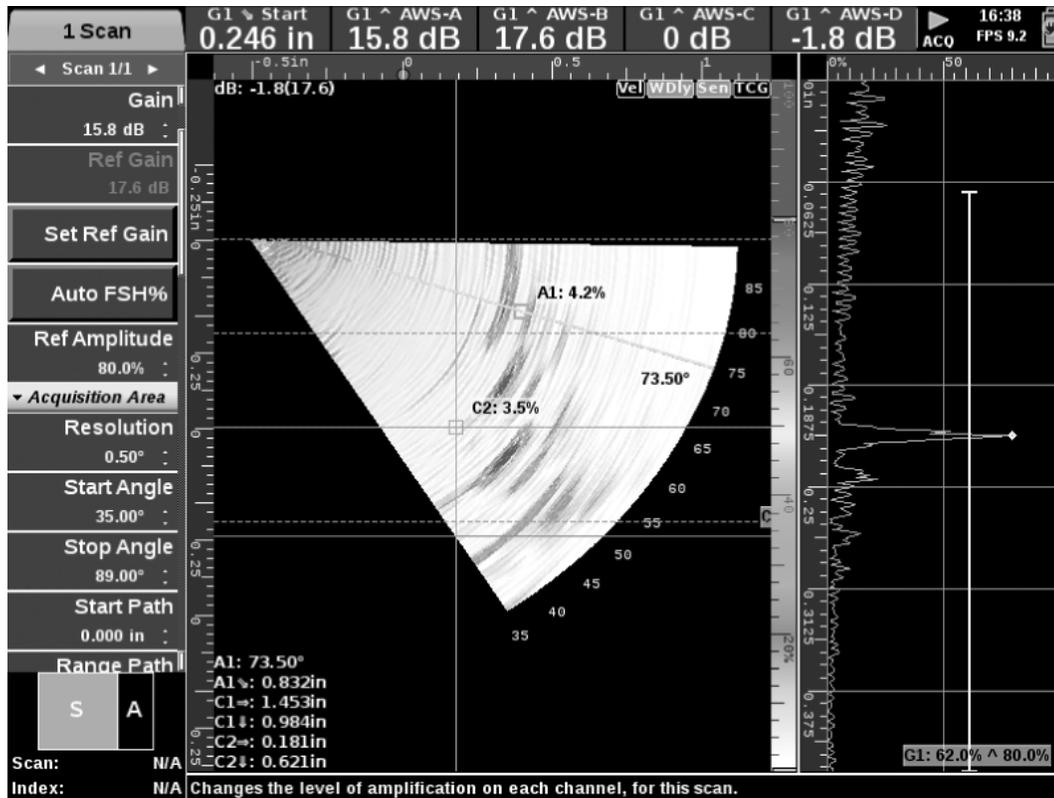
The primary advantages of the PAUT technique are the enhanced ability to inspect limited access areas and complex geometries and the ability to record scans to document and/or re-evaluate the inspection at a later date. An encoder may also be used when recording scans. An encoder is a device, normally in the form of a wheel that records probe position for computer analysis for an automatic data acquisition system. Encoded PAUT extends the ability of the recorded data to be re-evaluated at a later time, or transmit the data to another person or entity for review.

One of the advantages of PAUT for the examination of certain welds is that it may only require one line scan pass to obtain 100% volumetric inspection of a weld using the sectorial scan. Examination of the same weld using an electronic scan may take additional line scans to obtain 100% volumetric inspection of the weld.

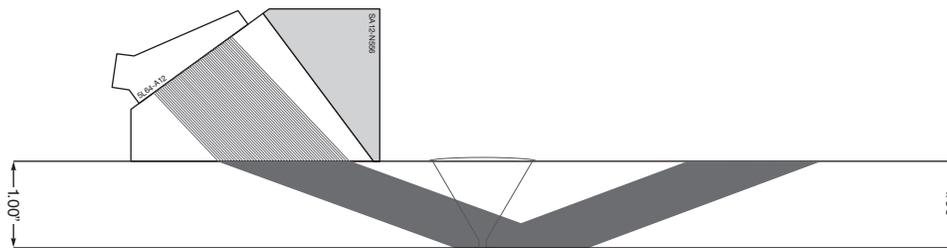
**5.5.2 Time of Flight Diffraction (TOFD).** The TOFD technique utilizes two angle beam probes placed in a transmitter-receiver position, one on each side of a weld. The transmitter emits a longitudinal wave that is picked up by the receiver. An A-scan display will show an indication from a surface traveling wave (called the “lateral wave”) and indications from the back wall. Between those indications will appear indications from any discontinuities that are present. Some sort of imaging is also usually employed. TOFD can simultaneously detect and size defects, and is among the most accurate techniques for sizing cracks. TOFD does have limitations, (e.g. limited near surface resolution capability) and is generally performed in conjunction with another technique of ultrasonic examination.



**Figure 28—Example of a Sectorial Scan (S-Scan)**



**Figure 29—Typical Analysis Window Showing a Sectorial Scan (Left) and a Corresponding A-Scan (Vertical, Right)**



**Figure 30—Example of an Electronic Scan (Linear or E-Scan)**

**5.6 Electromagnetic (ET).** Electromagnetic (Eddy current) examination (ET) can be defined as an electromagnetic nondestructive examination method in which small electrical currents are induced in a material, and any changes in the flow of these currents in the material are detected by a nearby coil for subsequent electronic processing and presentation. Its use for the examination of welds for surface or subsurface discontinuities is only one of the many applications (see Figure 31). Eddy current techniques have also been successfully applied to measure conductivity, grain size, hardness, and thickness; to identify materials with different composition, microstructure, magnetic permeability, and condition of heat treatment; and to determine the thickness of coatings and plating on various materials.

In eddy current examinations, an alternating current is passed through a coil placed in proximity to the weld. The alternating current in the coil creates an alternating magnetic field in the material. The alternating magnetic field in the weld, in turn, creates electrical currents (eddy currents) in the material. These eddy currents, which vary with the magnetic

field, create their own magnetic field which interacts with the initial field. The test coil, or in some cases a separate pickup coil, is electronically monitored to detect any changes in this field interaction. Discontinuities in the weld will alter the magnitude and direction of the eddy currents and thus be detected through the test signal. The signal is then displayed on the instrument. The most common display types are analog meter, digital readout, impedance plane, and time versus signal amplitude. Some instruments are capable of presenting data in several display formats.

A common coil used for weld examination is shown in Figure 32. Figure 32 shows an encircling coil which is used primarily on welded pipe with a longitudinal butt joint. Since the eddy currents flow in a circumferential direction, longitudinal discontinuities would produce the most significant change in eddy current flow. Hence, this technique would be most sensitive to longitudinally oriented discontinuities. The pipe is usually passed on rollers through the coil, which makes the technique suitable for automation. Their size, windings, and core (if any) vary with the type of material, orientation of discontinuities of interest, and size of the smallest discontinuity of interest.

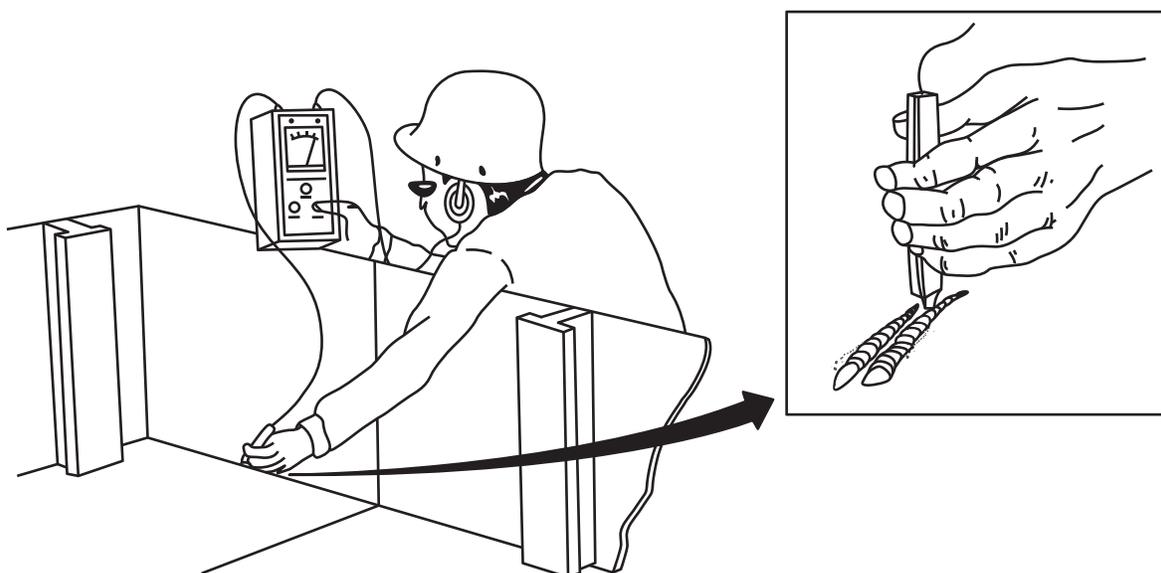
Several types of commonly used surface probes are shown in Figure 33. These probes can be used in any position and are usually hand manipulated.

Several advantages of using eddy current examination on welds include:

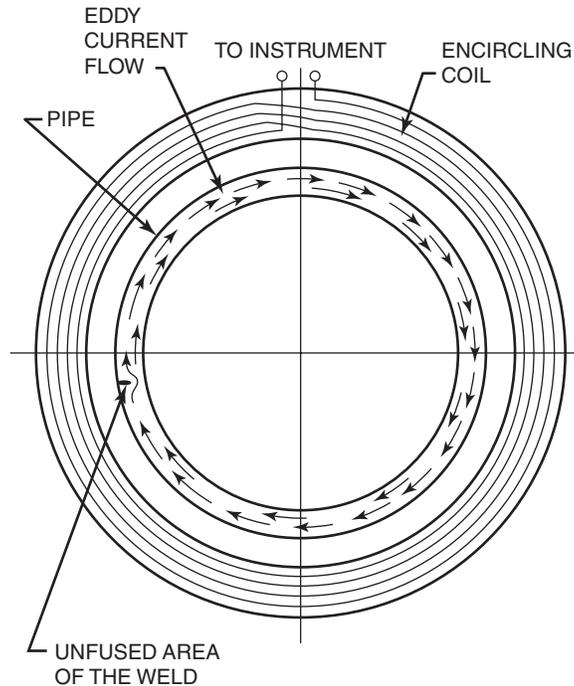
- (1) The equipment used with surface probes is generally lightweight and portable (see Figure 31).
- (2) Some weld surface conditions, such as excessive roughness and minor undercut, may result in irrelevant indications with other NDE methods. Welds with such conditions can usually be examined by eddy current techniques without the need to verify the indication's relevance by further processing (i.e., grinding to remove the surface irregularity and retesting).
- (3) Intimate contact between the weld metal and probe is not required, therefore painted or coated welds can be examined. This will also allow for the examination of hot surfaces and result in significant savings in the areas of in-service examinations and periodic preventive maintenance examinations.
- (4) In some instances, such as the examination of welded pipe, the process can be partially or completely automated to facilitate high speed, relatively inexpensive examination.

There are three general limitations in using eddy current examination on welds:

- (1) The test article (i.e., weld) must be an electrical conductor.
- (2) The depth of examination is generally limited to 6 mm [0.25 in] for nonferromagnetic materials and 0.25 mm [0.01 in] for ferromagnetic materials. The penetration in ferromagnetic materials may be significantly increased by using special techniques such as magnetic saturation of the area being examined.



**Figure 31—Eddy Current Weld Examination**



**Figure 32—Encircling Coil for the Eddy Current Examination of Welded Pipe**

(3) Since many variables can affect an eddy current signal (i.e., permeability, conductivity, probe position, and weld contour), care must be taken to suppress or separate variables of no concern from those of interest. Shielded probes may be used to accomplish this more readily.

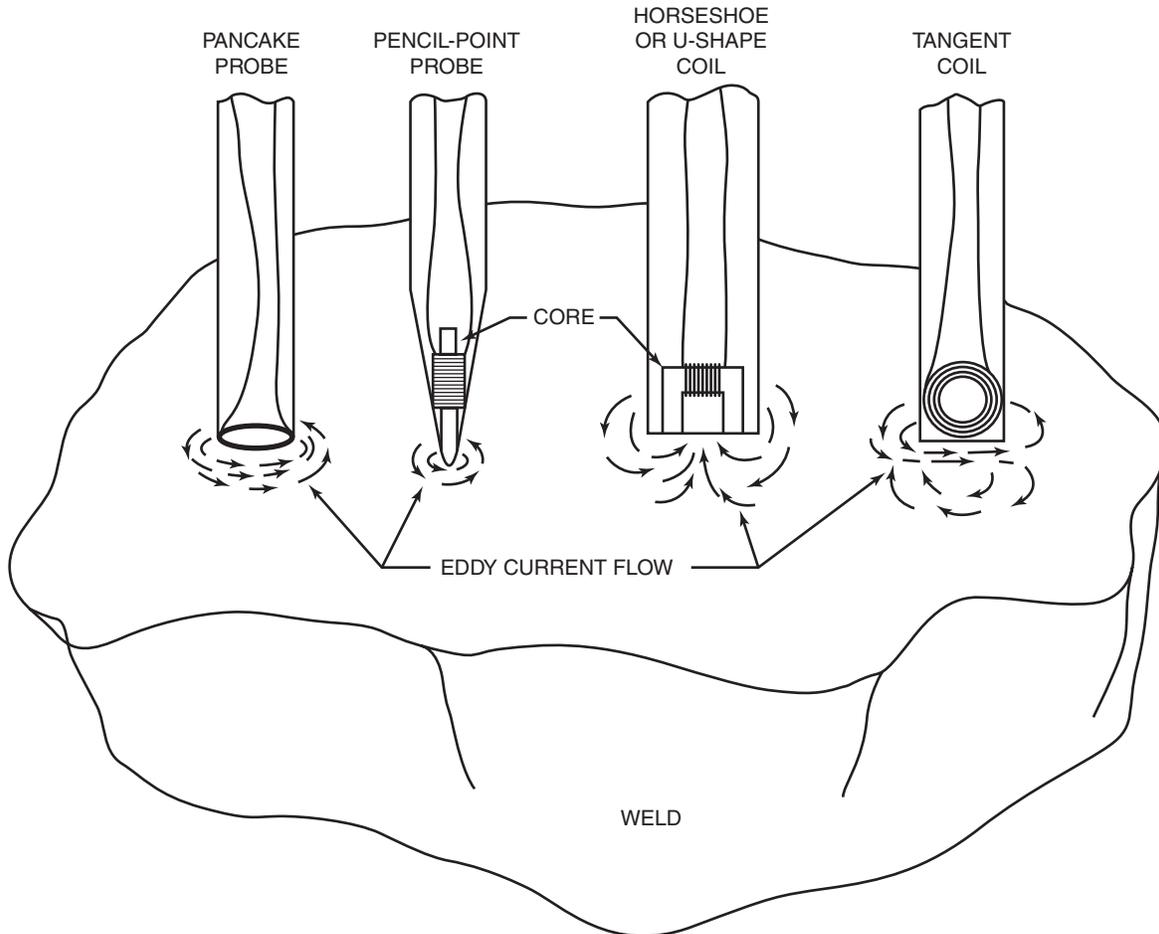
**5.7 Leak Testing (LT).** Leak testing is a method used to assess the ability of a component to contain or resist the introduction of a fluid or gas. This method can be used to test any component that can be pressurized or evacuated. Since welds are applied to join sections of these components together, leak testing of completed welds to determine their soundness is a common practice.

**5.7.1** Leak testing is a general term that applies to a number of different techniques. However, with each of these different tests, the basic principles are the same. The basic elements of a leak test are as listed below:

- (1) The introduction of a testing medium (gas or liquid) to the inside or outside of the component being tested.
- (2) Some pressure differential may be applied to enhance the movement of the testing medium through the component wall.
- (3) Observation of the surface opposite that to which the testing medium is applied for evidence of leaking through the component.

**5.7.2** The simplest form of a leak test is where a testing liquid is placed inside the test object. Then the component is examined for the presence of any test liquid that may have penetrated through the component by capillary action or flowing through a void. Filling some storage container with water and observing the outside of the vessel would be an example of such a leak test.

**5.7.3** A variation of this practice would be to apply some additional pressure to increase the mobility of the liquid through the component wall. Such is the case when a pressure vessel is subjected to a hydrostatic test, where water is the testing medium. This pressure may be provided by pumping the liquid at some high pressure or by introducing a gas in addition to the liquid testing medium. In some cases, the testing medium may be totally gaseous, as in the case of a pneumatic test, where compressed air is utilized.



**Figure 33 — Typical Eddy Current Surface Probes for the Examination of Welds**

**5.7.4** In cases where air or some other gas is utilized as the testing medium, its presence on the low pressure side of the component may be difficult to observe. To enhance the detection of the test medium, the component may be immersed in a liquid bath or sprayed with a leak test solution on the outside surface. If the gas has gained passage through the component wall, it will create bubbles in the liquid bath or leak test solution which can be easily detected visually.

**5.7.5** Vacuum box testing is a leak testing variation where the examiner only has access to one side of a component to be leak tested. Here, a leak test solution is applied to the test area and a rubber-gasketed enclosure with a clear viewing window is placed over the area. Using a bypass valve with an air compressor or a vacuum pump, the air is evacuated from the enclosure to produce a difference in pressure across the weld. If a leak exists, bubbles will form in the leak test solution. This technique is commonly employed for the testing of weld joints in the floors of storage tanks.

**5.7.6** Helium leak testing utilizes helium gas as the tracer gas. Helium is one of the smallest gas molecules and it is inert. It will not react with any of the materials in the test part. The test equipment will include a mass spectrometer tuned to detect helium, though other analyzers are available. This test method, which can be automated or performed manually, can identify smaller leaks than any other leak test technique. Leak rates are often measured at  $1 \times 10^{-6}$  mbar/second [ $1 \times 10^{-8}$  psi/second], though rates as low as  $1 \times 10^{-12}$  mbar/second [ $1 \times 10^{-14}$  psi/second] can be measured when the high vacuum method is used. For perspective, a  $1 \times 10^{-6}$  mbar/second [ $1 \times 10^{-8}$  psi/second] leak rate will take more than a year to fill a 50 mm [2in] cube. A leak rate of  $1 \times 10^{-12}$  mbar/second [ $1 \times 10^{-14}$  psi/second] would take more than a billion years to fill the same cube.

Helium leak testing is performed in one of two ways: High Vacuum Leak Testing (Outside-In) and High Pressure Leak Testing (Inside-Out, or “sniffer”). When performing the High Vacuum Leak Test, the part is evacuated and

helium is sprayed over it. In-line analyzers measure any leaking gas. When High Pressure Leak Testing, the part is pressurized with the tracer gas. A sniffing gun or sensor is positioned around the part to measure any leaking helium. In certain conditions test set-ups can be developed to perform both methods in conjunction with each other and recycle the helium gas.

Helium Mass Spectrometer Testing utilizes a gas of very small molecular size as the testing medium. Helium is the most commonly used gas for this purpose. There are two techniques utilized in Helium Mass Spectrometer Testing, “Outside-In” testing and “Inside-Out” testing. When performing the Inside-Out technique, helium is introduced into the test object under pressure. It is then detected on the opposite side of the component using special instruments such as a mass spectrometer with extremely sensitive calibrated leak standards. This form of leak testing provides extremely high sensitivity, or the ability to detect the smallest of leaks. The Sniffer Probe technique is also utilized when performing “Inside-Out” testing by “sniffing” or detecting any leakage of helium on the outside of the component. The Sniffer Probe is not as sensitive as the previous technique mentioned. When performing the Inside-Out technique, a helium mass spectrometer instrument is connected to the component and creates a vacuum inside. Helium is applied to the outside surface of the component, and any leakage is detected by the helium mass spectrometer. This technique is not as sensitive as the Inside-Out technique.

**5.7.7** Halogen Diode Leak Testing is a third method of leak detection. The most common form of this leak detection method uses halogen gases for a medium of inspection. Similar to the “Sniffer Probe” technique above, a halogen gas is introduced into the component and Halogen Leak Detector is used to detect any leakage on the outside. The other techniques are similar to the Helium Mass Spectrometer Testing, but instead of using helium, this requires a halogen containing compound gas.

**5.7.8** Absolute Pressure Leak Testing, often referred to as Absolute Pressure Change, is accomplished by introducing a specified amount of gas into the component and monitoring for any pressure change for a specified period of time.

## **6. Interrelationships Among Welding Processes, Discontinuities, and Examination Methods**

This clause includes several tables indicating particular relationships existing between welding processes, discontinuities, and examination methods. This information is provided as a reference only and should not be considered applicable for every specific examination situation.

Many factors which are beyond the scope of this guide affect these relationships. For example, Table 2 lists the discontinuities for each welding process that may occur under varying conditions and with many combinations of filler and base metals. When specific welding variables are controlled, depending on the type of filler and base metals, some of the discontinuities would not be expected to form.

Table 3 relates examination methods to the various types of discontinuities. Other factors also must be considered before the examination method may be reliably chosen for consistent results. For example, the shape of the weld, the compatibility of the material with the chosen method, and the welding process all affect the choice of method.

Table 4 relates joint types to applicable nondestructive examination methods. Again, further information is necessary before a preferred method can be chosen. Material type and shape, welding process, criticality level of the weldment, and unacceptable discontinuity types must be considered in selecting the most suitable examination method.

One should not attempt to draw conclusions by comparing one table to another. Each table stands by itself and is only provided as a general guide. If information beyond that presented by this document is needed, the informative references cited in Annex E should be reviewed, or a competent nondestructive examination consultant should be contacted.

Further information on the applicability of several of the nondestructive examination methods may be found in Annex A.

**Table 3**  
**Common Weld Examination Methods vs. Discontinuities**

Discontinuities	Examination Methods						
	RT	UT	PT <sup>a</sup>	MT <sup>b,d</sup>	VT <sup>a</sup>	ET <sup>b</sup>	LT <sup>c</sup>
Porosity	A	O	A	O	A	O	O
Slag inclusions	A	A	A	A	A	O	U
Incomplete fusion	O	A	A	A	A	O	O
Incomplete joint penetration	A	A	A	A	O	O	U
Undercut	A	U	A	A	A	O	U
Overlap	U	U	A	A	A	O	U
Cracks	O	A	A	A	A	A	O
Laminations	U	A	A <sup>c</sup>	A <sup>c</sup>	A <sup>c</sup>	U	U

<sup>a</sup> Surface.

<sup>b</sup> Surface and slightly subsurface.

<sup>c</sup> Weld preparation or edge of base metal.

<sup>d</sup> Magnetic particle examination is applicable only to ferromagnetic materials.

<sup>e</sup> Leak testing is applicable only to enclosed structures which may be sealed and pressurized during testing.

Legend:

RT—Radiographic examination

UT—Ultrasonic examination

PT—Liquid penetrant examination

MT—Magnetic particle examination

VT—Visual examination

ET—Electromagnetic examination

LT—Leak testing

A—Applicable method

O—Marginal applicability (depending on other factors such as material thickness, discontinuity size, orientation, and location)

U—Usually not used

**Table 4**  
**Applicable Examination Methods—Five Weld Joint Types**

Joints	Examination Methods						
	RT	UT	PT	MT	VT	ET	LT
Butt	A	A	A	A	A	A	A
Corner	O	A	A	A	A	O	A
T-	O	A	A	A	A	O	A
Lap	O	O	A	A	A	O	A
Edge	O	O	A	A	A	O	A

Legend:

RT—Radiographic examination

UT—Ultrasonic examination

PT—Liquid penetrant examination

MT—Magnetic particle examination

VT—Visual examination

ET—Electromagnetic examination

LT—Leak testing

A—Applicable method

O—Marginal applicability (depending on other factors such as material thickness, discontinuity size, orientation, and location)

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## Annex A (Informative)

# Examination Method Selection Guide

This annex is not part of this standard but is included for informational purposes only.

Typical Equipment	Applications	Advantages	Limitations
<b>Visual</b>			
Light source, magnifiers, color enhancement, protractors, other measurement equipment, i.e., rulers, micrometers, optical comparators.	Detection of surface discontinuities only. Verification of fit-up and joint configuration, weld dimensions, and profiles.	The method is economical and expedient, and requires relatively little training and relatively little equipment for many applications.	The method is limited to surface conditions only and by the experience and visual acuity of the inspector.
<b>Liquid Penetrant</b>			
Fluorescent or visible dye penetrant, developers, cleansers (solvents, emulsifiers, etc.). Suitable cleaning gear. Ultraviolet light source if fluorescent dye is used.	Detection of surface discontinuities only.	The equipment is portable and relatively inexpensive. The examination results are expedient. Results are easily interpreted. Requires no electrical energy except for light sources.	Surface films such as coatings, scale, smeared metal may mask or hide discontinuities. Bleed out from porous surfaces can also mask indications. Parts must be cleaned before and after examination.
<b>Magnetic Particle</b>			
Prods, yokes, coils suitable for inducing magnetism into the weld. Power source (electrical). Magnetic powders—some applications require special facilities and ultraviolet lights.	Detection of surface or near-surface discontinuities only.	The method is relatively economical and expedient. Examination equipment is considered portable. Unlike dye penetrants, magnetic particle can detect some discontinuities slightly below the surface.	The method is applicable only to ferromagnetic materials. Parts must be cleaned before and after examination. Thick coatings may mask rejectable discontinuities. Some applications require the part to be demagnetized after examination. Magnetic particle examination requires use of electrical energy for most applications.

Typical Equipment	Applications	Advantages	Limitations
<b>Radiography (Gamma)</b>			
Gamma ray sources, gamma ray camera projectors, film holders, film, lead screens, film processing equipment, film viewers, exposure facilities, radiation monitoring equipment.	Detection of voluminous discontinuities such as porosity, incomplete joint penetration, slag, etc. Lamellar type discontinuities such as cracks and incomplete fusion can be detected with a lesser degree of reliability. It may also be used in certain applications to evaluate dimensional requirements such as fit-up, root conditions, and wall thickness.	The method is generally not restricted by type of material or grain structure. The method detects surface and subsurface discontinuities. Radiographic images aid in characterizing discontinuities. The film provides a permanent record for future review. The gamma radiation method (especially Iridium 192) is portable.	Planar discontinuities must be favorably aligned with radiation beam to be reliably detected. Radiation poses a potential hazard to personnel. Cost of radiographic equipment, facilities, safety programs, and related licensing is relatively high. A relatively long time between exposure process and availability of results. Accessibility to both sides of the weld required. Use and disposal of processing chemicals.
<b>Radiography (X-rays)</b>			
X-ray sources (machines), electrical power source, same general equipment as used with gamma sources (above).	Same application as above.	Same as above, except that X-ray radiography can use adjustable energy levels, and it generally produces higher quality radiographs than gamma sources. The process also enjoys the same advantages as above.	High initial cost of X-ray equipment. Not generally considered portable. Also, same limitations as above.
<b>Ultrasonic</b>			
Pulse-echo, Phased Array Ultrasonic Testing (PAUT), and Time of Flight Diffraction (TOFD) instruments capable of exciting a piezoelectric material and generating ultrasonic energy within a weld, and a suitable cathode ray tube scope or digital display capable of displaying the magnitudes of received sound energy. Calibration standards, liquid couplant.	The method can detect most weld discontinuities including cracks, slag inclusions, and incomplete fusion. It can also be used to verify base metal thickness.	The method is most sensitive to planar type discontinuities. The test results are known immediately. The method is portable, and most ultrasonic flaw directors are battery operated. The method has high penetration capability. Method may be used when access to only one side of the joint is available.	Surface condition must be suitable for coupling of transducer. A liquid couplant is required. Small, thin welds may be difficult to inspect. Reference standards and a relatively skilled operator or inspector are required. Materials with large grain structures may be difficult to inspect. The method is less sensitive to rounded discontinuities.

Typical Equipment	Applications	Advantages	Limitations
<b>Eddy Current</b>			
An instrument capable of inducing electromagnetic fields within a weld and sensing the resulting electrical currents (eddy) so induced with a suitable probe or detector. Calibration standards.	Detection of discontinuities on or near the surface. Alloy content and heat treatment condition may affect results.	Equipment used with surface probes is generally lightweight and portable. Painted or coated welds can be inspected. The method can be partially or completely automated for a high speed, relatively inexpensive examination.	Relatively shallow depth of examination. Many material and test variables can affect the test signal.
<b>Leak Testing</b>			
Leak testing requires a gas or liquid medium, a pump to apply a differential pressure to one side of a weldment and a device to contain the pressure if the weldment is not a closed structure. A detection instrument, if the medium penetrating the weld cannot be detected visually, may also be required.	Detection of through thickness discontinuities	Relatively inexpensive and easy to do if visual detection of leaks is possible. Special mediums such as helium require more sophisticated equipment to detect. However, helium leak testing is very sensitive.	Requires a source of water or other medium, a means of disposing of the medium, and the weldment may require cleaning after testing.

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## Annex B (Informative)

### NDE Symbols and Abbreviations

This annex is not part of this standard but is included for informational purposes only. Further information is available in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

#### B1. Elements

The nondestructive examination symbol consists of the following elements:

- (1) Reference line;
- (2) Arrow;
- (3) Examination method letter designations;
- (4) Extent and number of examinations;
- (5) Supplementary symbols; and
- (6) Tail (specifications, codes, or other references).

#### B2. Examination Method Letter Designations

Nondestructive examination methods shall be specified by use of the letter designations shown below:

Examination Method	Letter Designation
Acoustic emission	AET
Electromagnetic	ET
Leak	LT
Magnetic particle	MT
Neutron radiographic	NRT
Penetrant	PT
Proof	PRT
Radiographic	RT
Ultrasonic	UT
Visual	VT

### B3. Supplementary Symbols

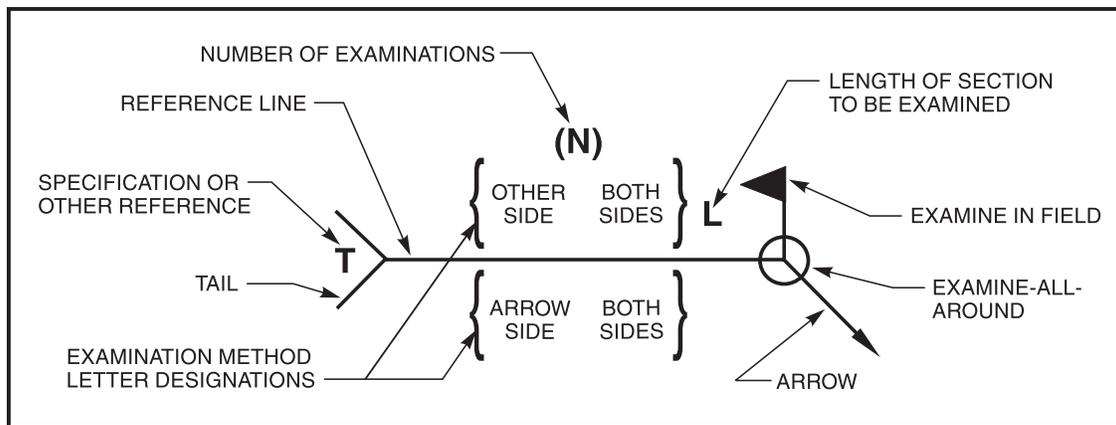
Supplementary symbols to be used in nondestructive examination symbols shall be as shown in Figure B.1.

### B4. Standard Location of the Elements

The elements of a nondestructive examination symbol shall have standard locations with respect to each other, as shown in Figure B.2.

EXAMINE ALL AROUND	FIELD EXAMINATION	RADIATION DIRECTION
		

**Figure B.1—Supplementary Nondestructive Examination Symbols**

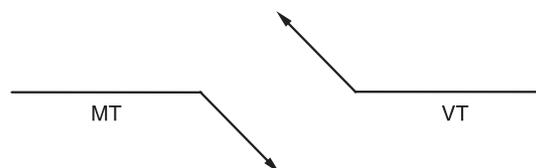


**Figure B.2—Standard Location of the Elements in the Nondestructive Examination Symbol**

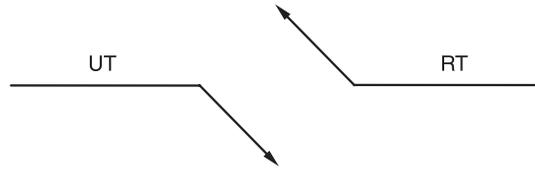
### B5. General Provisions for Nondestructive Examination Symbols

**B5.1 Location Significance of the Arrow.** The arrow shall connect the reference line to the part to be examined. The side of the part to which the arrow points shall be considered the arrow side. The side opposite the arrow side of the part shall be considered the other side.

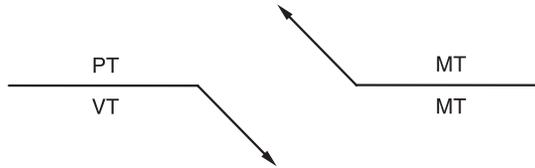
**B5.2 Location on the Arrow Side.** Examinations to be made on the arrow side of the part shall be specified by placing the letter designation for the selected examination method below the reference line.



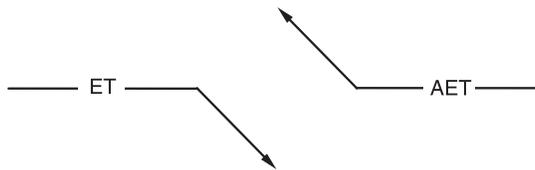
**B5.3 Location on the Other Side.** Examinations to be made on the other side of the part shall be specified by placing the letter designation for the selected examination method above the reference line.



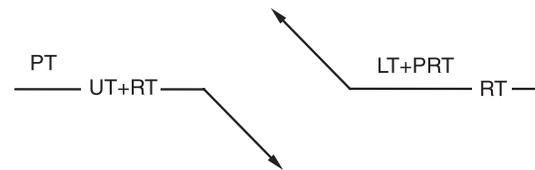
**B5.4 Location on Both Sides.** Examinations to be made on both sides of the part shall be specified by placing the letter designation for the selected examination method on both sides of the reference line.



**B5.5 Location Centered on the Reference Line.** When the letter designation has no arrow- or other-side significance, or there is no preference from which side the examination is to be made, the letter designation shall be centered on the reference line.

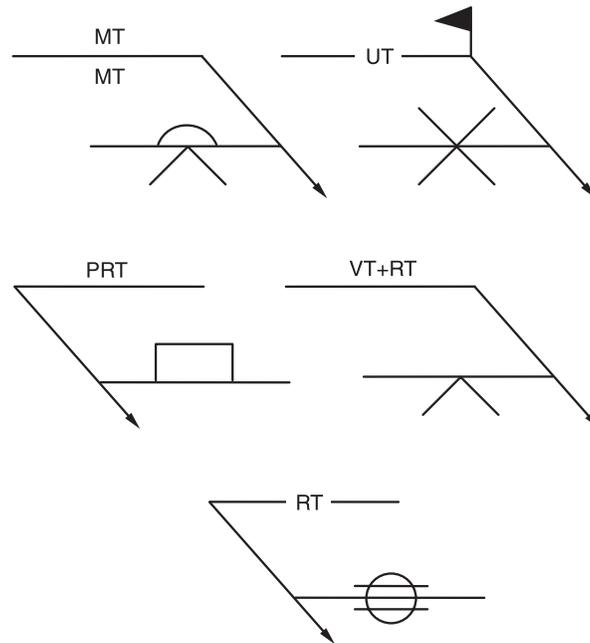


**B5.6 Examination Combinations.** More than one examination method may be specified for the same part by placing the combined letter designations of the selected examination methods in the appropriate positions relative to the reference line. Letter designations for two or more examination methods, to be placed on the same side of the reference line or centered on the reference line, shall be separated by a plus sign.



## B6. Welding and Nondestructive Examination Symbols

Nondestructive examination symbols and welding symbols may be combined.

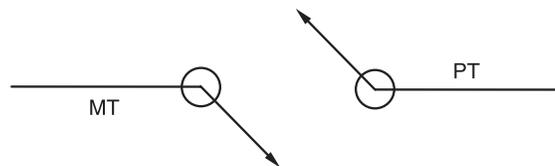


## B7. U.S. Customary and SI Units

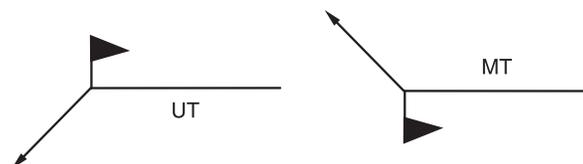
When it is required to specify dimensions with nondestructive examination symbols, the same system of units that is standard for the drawing shall be used. Dual dimensioning shall not be used on nondestructive examination symbols. If it is required to include conversions from SI to U.S. Customary units or vice versa, a table of conversions may be included on the drawing. For guidance in drafting standards, refer to the ANSI Y14, *Drafting Manual Series*. For guidance on the use of SI units, refer to AWS A1.1, *Metric Practice Guide for the Welding Industry*.

## B8. Supplementary Nondestructive Examination Symbols

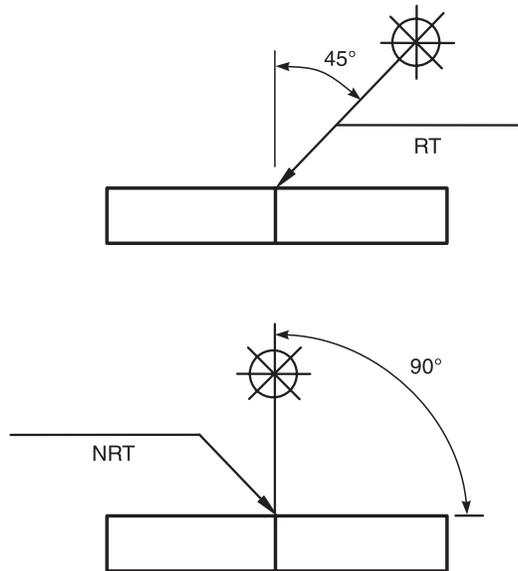
**B8.1 Examine-All-Around Symbol.** Examinations required all around a weld, joint, or part shall be specified by placing the examine-all-around symbol at the junction of the arrow and reference lines.



**B8.2 Field Examination Symbol.** Examinations required to be conducted in the field (not in a shop or at the place of initial construction) shall be specified by placing the field examination symbol at the junction of the arrow and reference lines.

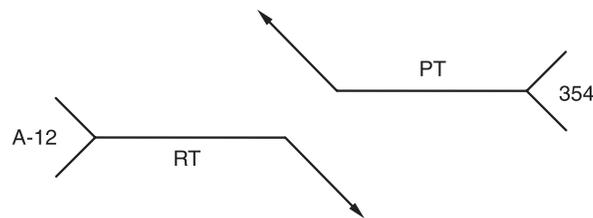


**B8.3 Radiation Direction Symbol.** The direction of penetrating radiation may be specified by use of the radiation direction symbol drawn at the required angle on the drawing and the angle indicated, in degrees, to ensure no misunderstanding.



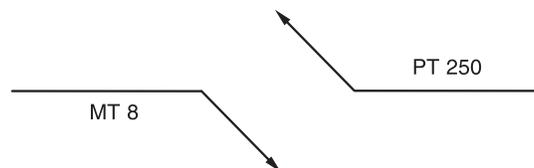
## B9. Specifications, Codes, and References

Information applicable to the examination specified and which is not otherwise provided may be placed in the tail of the nondestructive examination symbol.

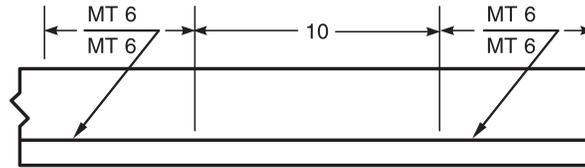


## B10. Extent, Location, and Orientation of Nondestructive Examination Symbols

**B10.1 Specifying the Length of the Section to be Examined.** To specify the examination of welds or parts where only a portion of the length of a section need be considered, the length dimension shall be placed to the right of the letter designation.

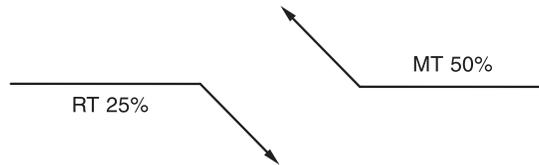


**B10.2 Location Shown.** To specify the exact location of a section to be examined, as well as the length, dimension lines shall be used.



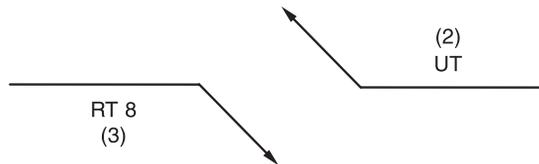
**B10.3 Full-Length Examination.** When the full length of a part is to be examined, no length dimension need be included in the nondestructive examination symbol.

**B10.4 Partial Examination.** When less than 100% of the length of a weld or part is to be examined, with locations to be determined by a specified procedure, the length to be examined is specified by placing the appropriate percentage to the right of the letter designation. The selected procedure may be specified by reference in the tail of the nondestructive examination symbol.



## B11. Number of Examinations

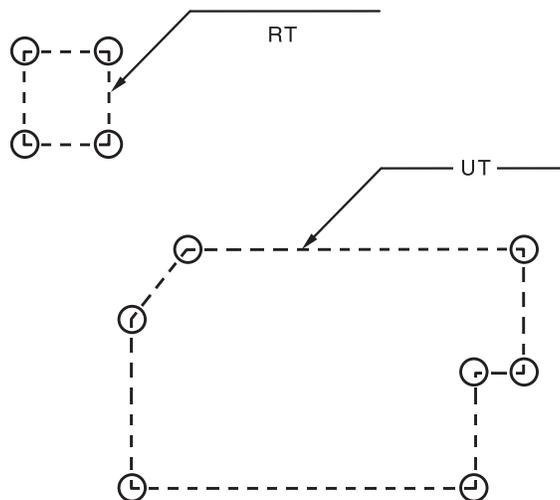
To specify a number of examinations to be conducted on a joint or part at random locations, the number of required examinations shall be placed in parentheses either above or below the letter designation away from the reference line.



## B12. Examination of Areas

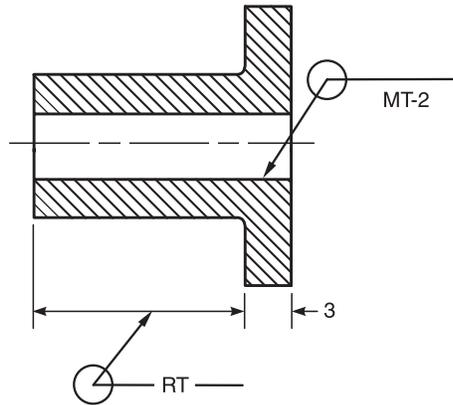
The nondestructive examination of areas shall be specified by one of the following methods:

**B12.1 Plane Areas.** To specify the nondestructive examination of an area represented as a plane on the drawing, the area to be examined shall be enclosed by straight, broken lines with a circle at each change in direction. The letter designations for the nondestructive examinations required shall be used in connection with these lines as shown below. When necessary, these enclosures shall be located by coordinate dimensions.

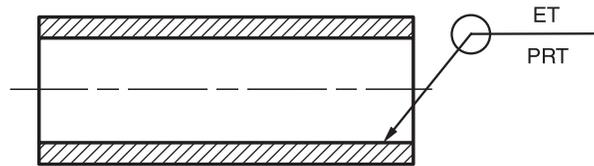


**B12.2 Areas of Revolution.** For nondestructive examination of areas of revolution, the area shall be specified by using the examine-all-around symbol and the appropriate dimensions. The illustration presented below specifies the following:

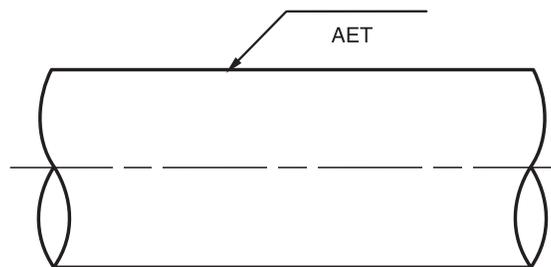
- (1) Magnetic particle examination of the bore of the flange for a distance of 51 mm [2 in] from the right-hand face, all the way around the circumference.
- (2) Radiographic examination of an area of revolution where dimensions were not available on the drawing.



The symbol shown below specifies an area of revolution subject to an internal proof examination and an external eddy current examination. Since no dimensions are given, the entire length is to be examined.



**B12.3 Acoustic Emission.** Acoustic emission examination (AET) is generally applied to all or a large portion of a component such as a pressure vessel or pipe. The symbol below indicates application of AET to the component without specific reference to location of sensors.



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## Annex C (Informative)

### Typical Industry Standards

This annex is not part of this standard but is included for informational purposes only.

Listed below are some of the standards used in the welding industry for fabrication and examination or inspection. They are listed here by name of category and society.

Category	Society	Title
Pressure Vessel	American Society of Mechanical Engineers (ASME) Two Park Avenue New York, NY 10016-5990 <a href="https://www.asme.org/">https://www.asme.org/</a>	Boiler and Pressure Vessel Code, Section V, Nondestructive Examination Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels
	Canadian Standards Association (CSA) 178 Rexdale Blvd. Toronto ON Canada M9W 1R3 <a href="http://www.csagroup.org">http://www.csagroup.org</a>	B51-Boiler, Pressure Vessel, and Pressure Piping Code N285.0 General Requirements for Pressure-Retaining Systems
Piping	American Society of Mechanical Engineers (ASME) Two Park Avenue New York, NY 10016-5990 <a href="https://www.asme.org/">https://www.asme.org/</a>	B31.1—Power Piping B31.3—Chemical Plant and Petroleum Refinery Piping B31.4—Liquid Petroleum Transportation Piping Systems Boiler and Pressure Vessel Code, Section V, Nondestructive Examination
	American Petroleum Institute (API) 1220 L Street N.W. Washington, DC 20005 <a href="http://www.api.org/">http://www.api.org/</a>	Standard 1104—Standard for Welding of Pipelines and Related Facilities API-RP-2X—Recommended Practice for Ultrasonic and Magnetic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Technicians
	Canadian Standards Association (CSA) 178 Rexdale Blvd. Toronto ON Canada M9W 1R3 <a href="http://www.csagroup.org">http://www.csagroup.org</a>	B51-Boiler, Pressure Vessel, and Pressure Piping Code Z662-Oil and Gas Pipeline Systems

(Continued)

Category	Society	Title
Structural	American Welding Society (AWS) 8669 NW 36 <sup>th</sup> St, #130 Miami, FL 33166 <a href="http://www.aws.org/">http://www.aws.org/</a>	D1.1/D1.1M—Structural Welding Code—Steel D1.2/D1.2M—Structural Welding Code—Aluminum D1.3/D1.3M—Structural Welding Code—Sheet Steel D1.4/D1.4M—Structural Welding Code—Reinforcing Steel D1.5/D1.5M—Bridge Welding Code D1.6/D1.6M—Structural Welding Code—Stainless Steel D1.7/D1.7M—Guide for Strengthening and Repairing Existing Structures D1.8/D1.8M—Structural Welding Code-Seismic Supplement D9.1M/D9.1—Sheet Metal Welding Code D3.6M—Underwater Welding Code D14—series of AWS Specifications on industrial welding specifications on machinery and equipment including: Specification for Welding of Earthmoving, Construction, and Agricultural Equipment and Others. D15.1—series of AWS railroad welding specifications, including Railroad Welding Specification for Cars and Locomotives D18—series of AWS welding Specifications for sanitary applications including: Specification for Welding Austenitic Stainless Steel Tube and Pipe Systems in Sanitary (Hygienic) Applications B5.1, Specification for the Qualification of Welding Inspectors B5.2, Specification for the Qualification of Welding Inspector Specialists and Welding Inspector Assistants
	American Institute of Steel Construction (AISC) 130 East Randolph Street Suite 2000 Chicago, IL 60601 <a href="http://www.aisc.org/">http://www.aisc.org/</a>	AISC N690, Specification Safety Related Structures for Nuclear Facilities, Chapters NM and NN AISC 360, Specification for Structural Steel Buildings, Chapters M and N
	Canadian Standards Association (CSA) 178 Rexdale Blvd. Toronto ON Canada M9W 1R3 <a href="http://www.csagroup.org">http://www.csagroup.org</a>	W59-Welded Steel Construction
Shipbuilding	American Bureau of Shipping (ABS) 16855 Northchase Drive Houston, TX 77060 <a href="http://www.eagle.org/">http://www.eagle.org/</a>	Rules for Building and Classing Steel Vessels, Part 2-Rules for Materials and Welding Guide for Nondestructive Inspection of Hull Welds
	DNV GL Veritasveien 1 1363 Hovik Norway <a href="http://www.dnvgl.com">http://www.dnvgl.com</a>	Rules for Classification of Ships, Part 2-Materials & Welding Rules for Classification of Ships, Part 3-Fabrication and Testing of Ships

(Continued)

<b>Category</b>	<b>Society</b>	<b>Title</b>
	International Association of Classification Societies (IACS) 6th Floor, 36 Broadway London UK SW 1H 0BH <a href="http://www.iacs.org.uk">http://www.iacs.org.uk</a>	IACS Unified Requirements: Section W-Materials and Welding
	Lloyd's Register Group Ltd. (LR) 71 Fenchurch St. London UK EC3M 4BS <a href="http://www.lr.org">http://www.lr.org</a>	Lloyd's Register's Rules and Regulations for the Classification of Ships: Rules for the Manufacture, Testing, and Certification of Materials

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## Annex D (Informative)

# Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

### D1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

### D2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

### D3. General Procedure for all Requests

**D3.1 Submission.** All requests shall be sent to the Managing Director of AWS Technical Services Division. For efficient handling, it is preferred that all requests should be submitted electronically through [technical@aws.org](mailto:technical@aws.org). Alternatively, requests may be mailed to:

Managing Director  
Technical Services Division  
American Welding Society  
8669 NW 36 St, # 130  
Miami, FL 33166

**D3.2 Contact Information.** All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

**D3.3 Scope.** Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

**D3.4 Question(s).** All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point

is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

**D3.5 Proposed Answer(s).** The inquirer shall provide proposed answer(s) to their own question(s).

**D3.6 Background.** Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

## **D4. AWS Policy on Interpretations**

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

## **D5. AWS Response to Requests.**

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the Welding Journal, and post it on the AWS website.

## **D6. Telephone Inquiries**

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The AWS Board Policy Manual requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

## Annex E (Informative)

### Informative References

This annex is not part of this standard but is included for informational purposes only.

- (1) Krautkramer, J., and H. Krautkramer, *Ultrasonic Testing of Materials*, New York, NY: Springer-Verlag, Inc.
- (2) *Nondestructive Evaluation and Quality Control*, 9th Ed., ASM Metals Handbook, Vol. XVII, Metals Parks, OH: ASM International.
- (3) *Nondestructive Handbook Series*, Harrisburg, NC; PH Diversified, Inc. [Programmed Instruction (Self Study) and Classroom Training (Reference Texts) available in introduction to NDT, liquid penetrant, magnetic particle, ultrasonic, eddy current testing methods.]
- (4) *Radiography in Modern Industry*, 4th Ed., Rochester, NY: Eastman Kodak Co.
- (5) Connor, L. P., *Welding Handbook*, 9th Ed. Vol. 1, Miami, FL: American Welding Society.
- (6) *Nondestructive Testing Handbook*, Third Edition, Columbus, OH; American Society for Nondestructive Testing.
- (7) NDT Handbook: Volume 1, Leak Testing, McMaster, Robert C. (ed. Emeritus), Mester, Michael (tech ed.), American Society for Nondestructive Testing, Columbus, OH.
- (8) NDT Handbook: Volume 2, Liquid Penetrant Tests, Tracy, Noel (tech ed) and Moore, Patrick (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (9) NDT Handbook: Volume 3, Radiography and Radiation Testing, Bryant, Lawrence E. (tech ed.) and McIntire, Paul (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (10) NDT Handbook: Volume 4, Electromagnetic Testing, McMaster, Robert C. (ed. Emeritus), Mester, Michael (tech. ed.) and McIntire, Paul (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (11) NDT Handbook: Volume 5, Acoustic Emission Testing, Miller, Ronnie K. (tech. ed.) and McIntire Paul (ed.) American Society for Nondestructive Testing, Columbus, OH.
- (12) NDT Handbook: Volume 7, Ultrasonic Testing, Birks, Albert S. (tech. ed.), Green, Robert E. Jr. (tech. ed.), and McIntire, Paul (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (13) NDT Handbook: Volume 8, Visual and Optical Testing, Allgaier, Michael W. (tech. ed) Ness, Stanley (tech. ed.), McIntire, Paul (ed.) and Moore, Patrick O. (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (14) NDT Handbook: Volume 9, Special Nondestructive Testing Methods, Stanley, Roderick K. (tech.ed.), Moore, Patrick O. (ed.), and McIntire, Paul (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (15) NDT Handbook: Volume 10, NDT Overview, Ness, Stanley (tech. ed.), Sherlock, Charles N. (tech. ed), Moore, Patrick O. (ed.), and McIntire, Paul (ed.), American Society for Nondestructive Testing, Columbus, OH.
- (16) ANSI/ASNT CP-105, ASNT Standard Topical Outlines for Qualification of Nondestructive Testing Personnel, Columbus, OH, American Society for Nondestructive Testing.

- (17) Recommended Practice No. SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*, Columbus, OH: American Society for Nondestructive Testing.
- (18) Center for NDE-Iowa State University: [www.cnde.iastate.edu](http://www.cnde.iastate.edu)
- (19) Iowa State NDT Educational site: [www.ndt-ed.org](http://www.ndt-ed.org) or [www.nde-ed.org](http://www.nde-ed.org)
- (20) American Society of Nondestructive Testing (ASNT): [www.asnt.org](http://www.asnt.org)
- (21) On-line Journal of Nondestructive Testing: [www.ndt.net](http://www.ndt.net)
- (22) NDT&E International Journal: [www.sciencedirect.com/science/journal/09638695](http://www.sciencedirect.com/science/journal/09638695)
- (23) AWS QC1, *Standard for AWS Certification of Welding Inspectors*, Miami, FL; American Welding Society.
- (24) AWS B5.1, *Specification for the Qualification of Welding Inspectors*, Miami, FL; American Welding Society.
- (25) AWS B5.2, *Specification for the Qualification of Welding Inspector Specialists and Welding Inspector Assistants*, Miami, FL; American Welding Society.
- (26) AWS B5.15, *Specification for the Qualification of Radiographic Interpreters*, Miami, FL; American Welding Society.

**List of AWS Documents on Weld Inspection**

<b>Designation</b>	<b>Title</b>
B 1.10M/B 1.10	<i>Guide for the Nondestructive Examination of Welds</i>
B 1.11M/B1.11	<i>Guide for the Visual Inspection of Welds</i>
WIH	<i>Welding Inspection Handbook</i>

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