8.9.2.6 Time of Flight Diffraction (TOFD) B-Scan and D-Scan Displays (see Figure 52 and Figure 53)

The B-scan and D-scan displays are a different format than the B-scan and D-scan displays acquired in any other ultrasonic technique utilizing information provided in a pulse echo fashion. TOFD B-scan and D-scan images provide defect sizing information for through-wall extent by using diffracted signals rather than pulse echo signals. The TOFD B-scan and D-scan displays are created by stacking A-scan displays at a preset interval or collection step and viewing the data in a grayscale image where 100 % amplitude of the sine wave in either the positive or negative direction is plotted as all black or all white with gray images of signals less than 100 % amplitude.

TOFD passes sound energy through a weld area by utilizing a transmitting transducer on one side of the weld and a receiving transducer on the other (see Figure 54). Any changes in the material, such as discontinuities, are vibrated by the induced ultrasonic energy. This vibration of discontinuities produces diffracted signals from the discontinuity that are then received by the receiving transducer.

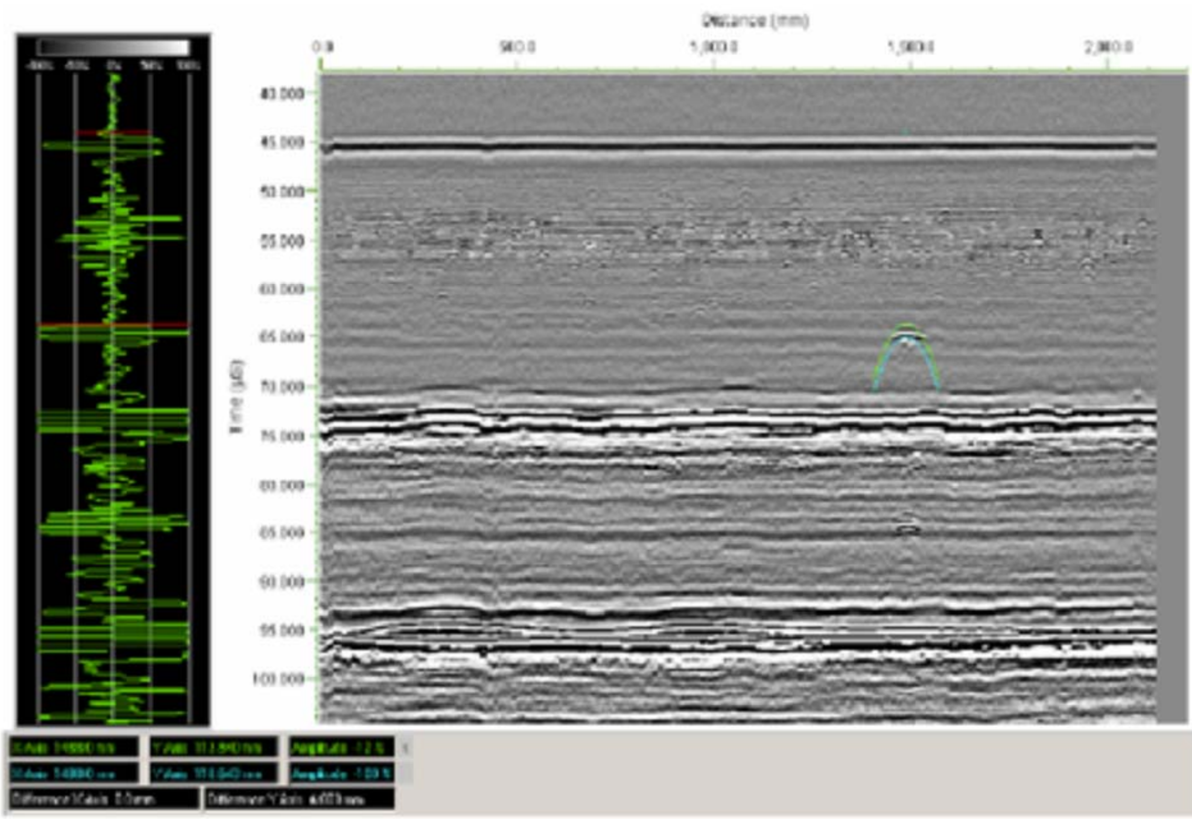


Figure 52—TOFD D-Scan Display

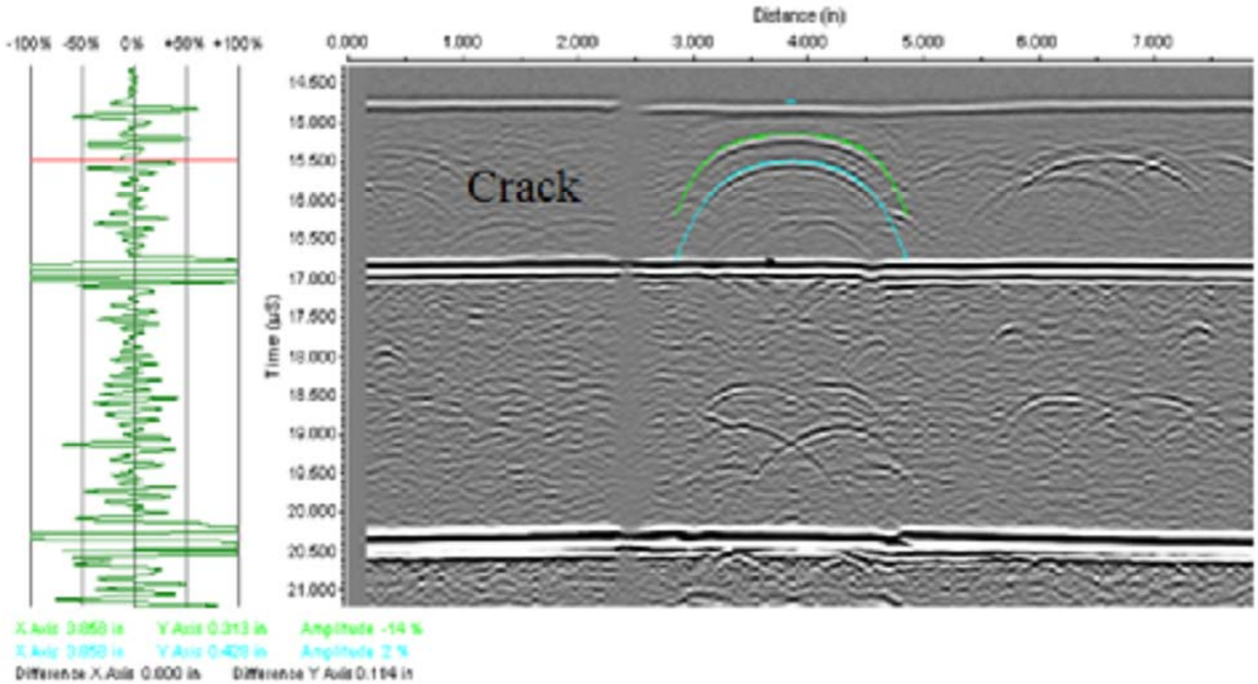
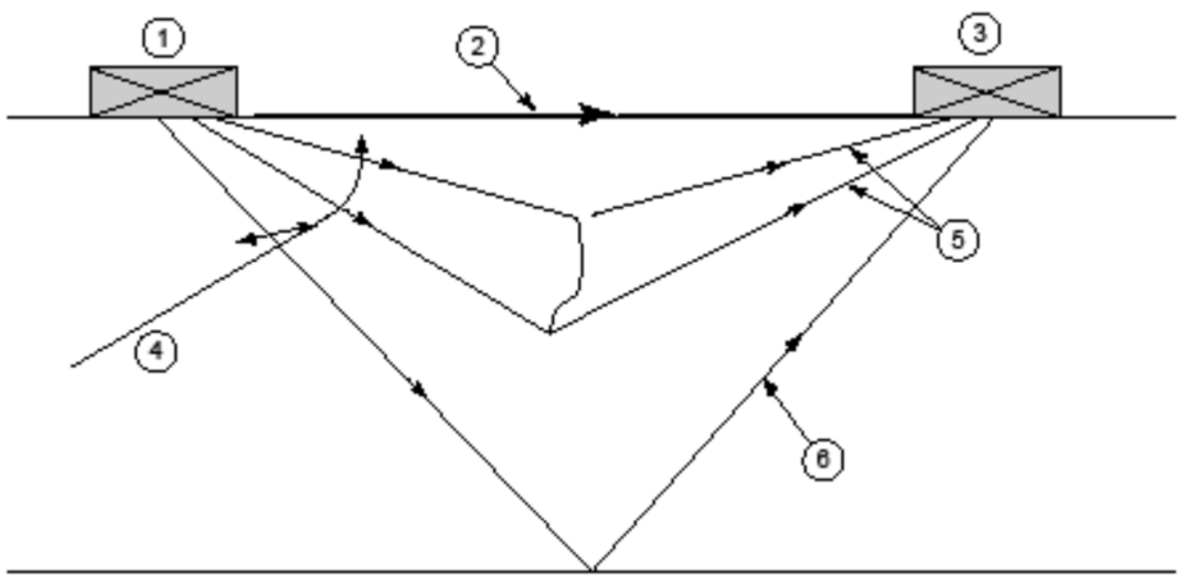


Figure 53—TOFD B-Scan



Key
1 transmitter
2 lateral wave
3 receiver
4 longitudinal wave and shear wave beam spread
5 diffracted energy from flaw tips
6 back wall echo

Figure 54—TOFD Transducer Arrangement and Ultrasonic Energy Beam Propagation

The set of TOFD probes can be manipulated along a weld or across a weld to create scans. Standard TOFD weld inspection is accomplished by moving TOFD probes along the weld, with one transducer on each side of the weld, where the ultrasonic energy is perpendicular to the weld. This is a TOFD D-scan or nonparallel scan. The TOFD probes can also be manipulated across an area parallel to the sound path to evaluate an indication from a position 90° from the perpendicular imaging. This is a TOFD B-scan or parallel scan. This can only be accomplished if the weld cap has been removed for the purpose of weld inspection, and is most often used to provide more accurate imperfection location information once they have been located with the TOFD D-scan.

8.9.2.7 Requirements for Ultrasonic Inspection

ASME Section V, Article 4, lists the general requirements for ultrasonic examination. Codes and specifications may indicate that compliance with these requirements is mandatory. ASME B31.3 and ASME Section VIII, Division 1, requires ultrasonic examination be performed in accordance with ASME Section V, Article 4, which requires a written procedure to be qualified and followed. Some procedural requirements to be included are:

a) weld, base metal types, and configurations to be examined;

b) technique (straight or angle beam);

c) couplant type;

d) ultrasonic instrument type;

e) instrument linearity requirements;

f) description of calibration;

g) calibration block material and design;

h) inspection surface preparation;

i) scanning requirements (parallel and perpendicular to the weld);

j) scanning techniques (manual or automated);

k) evaluation requirements;

l) data to be recorded;

m) reporting of indications in terms of the acceptance standards of the referencing code;

n) postexamination cleaning.

8.9.3 Ultrasonic Examination System Calibration

8.9.3.1 General

Ultrasonic examination system calibration is the process of adjusting the controls of the ultrasonic instrument such that the UT display of the sound path is linear. Calibration is to ensure that there is sufficient sensitivity to detect discontinuities of the size and type expected in the product form and process.

The inspection system includes the examiner, the ultrasonic instrument, cabling, the search unit including wedges or shoes, couplant, and a reference standard. The search unit transducer should be of a size, frequency, and angle capable of detecting the smallest rejectable defect expected to be in the part being examined. The ultrasonic instrument is required to meet the requirements of ASME Section V, Article 5, Paragraph T-530, and should provide the functionality to produce the required display of both the calibration reflectors and discontinuities located during the examination.

The reference standard (calibration block) should have the same composition and heat treatment condition as the product being examined. It should also have the same surface condition as the part being examined. The reference standard should be of an acceptable size and have known reflectors of a specified size and location. These reflectors should be acceptable to the referencing code. ASME Section V, Article 4, Figure T-434.2.1 and Figure T-434.3, details the requirements for basic calibration block construction.

Calibration system checks are required to be performed prior to and at the completion of an examination. In addition, a system check is required with any change in the search unit, cabling, and examiner, and after a specified time frame, such as four hours. The temperature of the calibration standard should be within 25 °F (14 °C) of the part to be examined. If the temperature falls out of that range, the reference standard is brought to within 25 °F (14 °C), and a calibration check should be performed. For high-temperature work, special high-temperature transducers and couplants are usually necessary. Consideration should be given to the fact that temperature variations within the wedge or delay line can cause beam angle changes or alter the delay on the time base. System checks are typically performed at a minimum of every four hours during the process of examination, but can be done more often at the examiner's discretion after any instance of suspected system irregularity.

If, during a system calibration check, it is determined that the ultrasonic equipment is not functioning properly, all areas tested since the last successful calibration should be re-examined.

8.9.3.2 Echo Evaluation With Distance Amplitude Correction

The distance amplitude correction (DAC) curve allows an echo evaluation of unknown reflectors by comparison of the echo height with respect to the DAC (%DAC).

Due to attenuation and beam divergence inherent to all materials, the echo amplitude from a given size reflector decreases as the distance from the probe increases. To set up a DAC curve, the maximum response from a specified reference reflector (e.g. flat bottom or side drilled hole) is recorded at different depths over the required test range. The calibration block with reference reflectors should be of the same material as the part under test. The curve is plotted through the peak points of the echo signals from the reflectors as shown in Figure 55. The curve represents the signal amplitude loss based upon distance, from the same size reference reflector using a given probe. The gain setting used to establish the DAC during the initial calibration is referred to as the primary reference level sensitivity. Evaluation is performed at this sensitivity level.

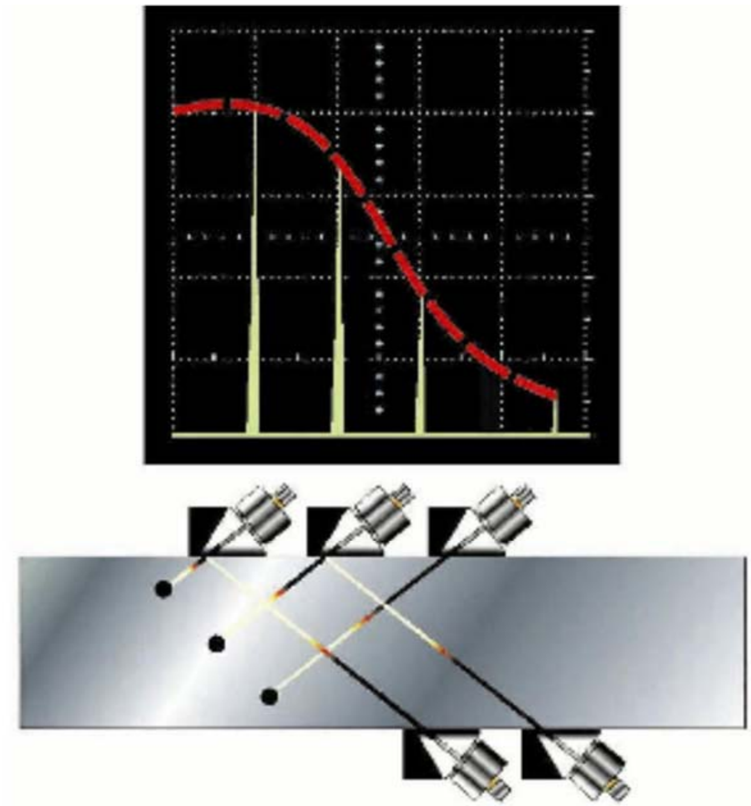


Figure 55—DAC Curve for a Specified Reference Reflector

Unknown reflectors (flaws) are evaluated by comparing their echo amplitude against the height of the DAC curve (i.e. 50 % DAC, 80 % DAC, etc.) at the sound path distance of the unknown reflector (see Figure 56). Material characteristics and beam divergence are automatically compensated for because the reference block and the test object are made of the same material, and have the same heat treatment and surface condition.

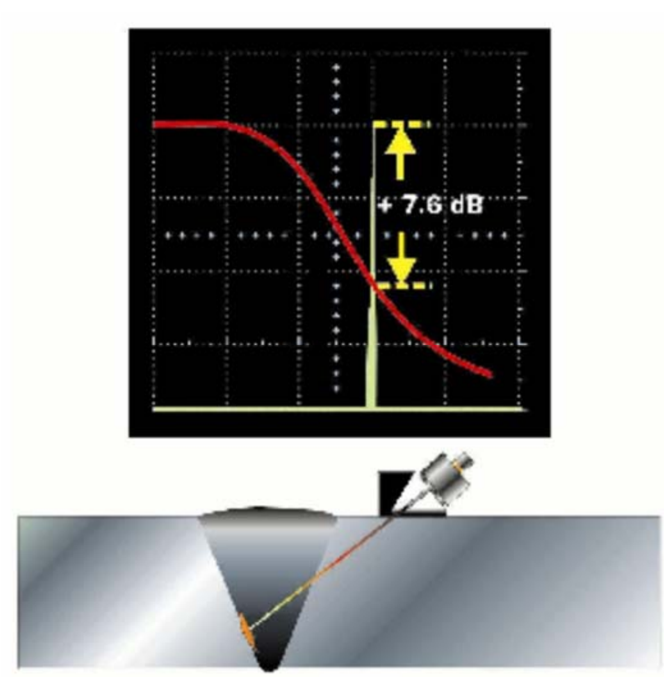


Figure 56—DAC Curve for an Unknown Reflector

8.9.4 Surface Preparation

Prior to ultrasonic examination, all scan surfaces should be free from weld spatter, surface irregularities, and foreign matter that might interfere with the examination. The weld surface should be prepared such that it permits a meaningful examination.

8.9.5 Examination Coverage

The volume of the weld, HAZ, and a portion of the adjacent base material on both sides of the weld should be examined by moving the search unit over the examination surface in order to scan the entire examination volume. Each pass of the transducer should overlap the previous pass by at least 10 % of the transducer element dimension. The rate of search unit movement should not exceed 6 in. (150 mm) per second unless the calibration was verified at an increased speed, and the instrument is capable of resolving imperfections at that speed. In many cases, the search unit is oscillated from side to side to increase the chances of detecting fine cracks that are oriented other than perpendicular to the sound beam.

8.9.6 Straight Beam Examination

A straight beam examination should be performed adjacent to the weld to detect reflectors that would interfere with the angle beam examining the weld, such as a lamination in the base material. All areas having this type of reflector should be identified as the system response in these areas will be different from that in unaffected locations.

8.9.7 Angle Beam Examination

8.9.7.1 General

Typically, there are two different angle beam examinations performed on a weld: a scan for reflectors that are oriented parallel to the weld, and a scan for reflectors that are oriented transverse to the weld. In both cases, the scanning should be performed at a gain setting at least two times (+6 dB) the reference level sensitivity established during calibration. Evaluation of indications, however, should be performed at the primary reference level sensitivity. In both cases, the search unit should be manipulated such that the ultrasonic energy passes through the required volume of the weld and HAZ.

During examination for reflectors that are oriented parallel to the weld, the sound beam is directed at approximate right angles to the weld, preferably from both sides of the weld. For reflectors that are oriented transverse to the weld, the sound beam is directed parallel to the weld and a scan is performed in one direction around the weld, then the search unit is turned 180° and another scan is performed until the ultrasonic energy has passed through the required volume of weld and HAZ in two directions.

To inspect for transverse flaws, the angle beam transducers should be rotated 90°, or additional transverse flaw inspection using other techniques may be performed to supplement automated ultrasonic weld inspection techniques.

8.9.7.2 Supplemental Angle Beam Examination

When inspecting a weld with TOFD, the presence of the lateral wave and back-wall indication signals may obscure detection of flaws present in these zones. ASME BPVC, Section V, requires that the weld's near and far surfaces (i.e. both top and bottom surfaces) be examined by angle beam with the angles chosen that are closest to being perpendicular to the weld interfaces. This examination may be performed manually or mechanized; if mechanized, the data should be collected in conjunction with the TOFD examination.

8.9.8 Automated Ultrasonic Examination (AUT)

Volumetric Inspection of welds may be performed using one of the four automated ultrasonic weld inspection techniques.

a) Pulse Echo Raster Scanning: This technique inspects with zero degree compression and two angle beam transducers interrogating the weld from either side simultaneously. The compression transducers examine for corrosion or laminar defects in the base metal and the angle beam transducers scan the volume of the weld metal.

b) Pulse Echo Zoned Inspection: The zoned inspection is a line scan technique. The technique uses an array of transducers on either side of the weld with the transducer angles and transit time gates set to ensure that the complete volume of the weld is inspected.

c) Time of Flight Diffraction (TOFD): This is a line scan technique used in the pitch-catch mode. The multimode transducers are used to obtain the maximum volume inspection of the weld region. More than one set of transducers may be required for a complete volumetric inspection.

d) Phased Array (PA) Inspection: This technique utilizes an array of transducer elements to produce steering of the ultrasonic beam axis or focusing of the ultrasonic beam over a specified range. This allows the user the ability to inspect certain portions or zones of the component being tested using many different beam angles.

8.9.9 Discontinuity Evaluation and Sizing

8.9.9.1 General

UT procedures should include the requirements for the evaluation of discontinuities. Typically, any imperfection that causes an indication in excess of a certain percentage of DAC curve should be investigated in terms of the acceptance standards. The procedure should detail the sizing technique to be used to plot the through-thickness dimension and length.

One commonly used sizing technique is called the “intensity drop” or “6 dB drop” technique. This sizing technique uses the beam spread of the transducer to quickly estimate the axial length of the reflector. Using this technique, the transducer is positioned on the part such that the amplitude from the reflector is maximized. This point is marked with a grease pencil. The UT instrument is adjusted to set the signal to 80 % full screen height (FSH). The transducer is then moved laterally until the echo has dropped to 40 % FSH (6 dB). This position is also marked. The transducer is then moved laterally in the other direction, past the maximum amplitude point, until the echo response again reaches 40 % FSH. This point is marked with the grease pencil. The two outside marks produce the approximate axial size of the flaw.

Other sizing techniques should be used to obtain a more precise measurement of the length and through-wall dimension of the flaw. With advances in technologies, a number of other through-thickness sizing techniques are described in Sections 9.9.9.2–9.9.9.5.

8.9.9.2 ID Creeping Wave Method

The inside diameter (ID) creeping wave method uses the effects of multiple sound transfer modes, such as longitudinal waves and shear waves to qualitatively size flaws. The method is used for the global location of flaws in the bottom $^1/_3$, middle $^1/_3$, and top $^1/_3$ regions of the object/weld. Three distinct waves are presented with the ID creeping wave method:

a) High-angle refracted longitudinal wave of approximately 70°;

b) direct 30° shear wave which mode converts to a 70° refracted longitudinal wave;

c) indirect shear or “head” wave which mode converts at the inside diameter from a shear wave to a longitudinal wave, and moves along the surface.

8.9.9.3 Tip Diffraction Method

Tip diffraction methods are very effective for sizing flaws that are open to the inside or outside diameter surface. For ID connected flaws, the half "V" path or one and one half "V" path technique is used. For outside diameter (OD) connected flaws, two techniques are available: the time-of-flight tip diffraction technique and the time measurement technique of the tip diffracted signal and the base signal.

8.9.9.4 High-Angle Longitudinal Method

The high-angle refracted longitudinal wave method is very effective for very deep flaws. Dual-element, focused, 60, 70, and OD creeping waves are used to examine the outer one-half thickness of the component material. Probe designs vary with the manufacturer. Depth of penetration is dependent upon angle of refraction, frequency, and focused depth. Many of these transducers are used not only for sizing, but also for detection and confirmation of flaws detected during the primary detection examination. For coarse-grain materials, these probes work well where shear-wave probes are ineffective.

8.9.9.5 Bimodal Method

The bimodal method is a dual-element tandem probe with the transducer crystals located one in front of the other. The probe also generates an ID creeping wave. The wave physics are essentially the same. The pseudofocusing effect of the dual-element crystals is very effective for ID connected flaws in the mid-wall region, 30 % to 60 % through the wall depth. A low-angle shear wave (indirect) mode converts at the ID to produce an ID creeping wave, which detects the base of the flaw. A further low-angle shear-wave mode converts at the ID to a longitudinal wave, which reflects a longitudinal wave from the flaw face. A high-angle refracted longitudinal wave detects the upper extremity of the flaw (70°). The bimodal method can be used to confirm the depth of shallow to deep ID connected flaws. However, very shallow flaws of less than 10 % to 20 % tend to be slightly oversized, and very deep flaws tend to be slightly undersized.

Significant training and experience are required to effectively utilize some of the more advanced UT detection and sizing techniques.

8.9.9.6 Phased Array Method

The phased array method utilizes an array of transducer elements, excited in precise timing patterns, to produce steering or focusing of the ultrasonic beam over a specific range of angles in the component being inspected. The system consists of a computerized ultrasonic pulser/receiver instrument that contains the collection setup and analysis software, an umbilical cable, and the phased array probe/wedge. The phased inspection may be performed manually, or with an encoder for semi-automated scans, or with a mechanized scanner for fully automated scanning.

The method allows the user the ability to inspect certain portions or zones of the component under test using many different beam angles. The results may be viewed as A-scan, B-scan, C-scan, or as Sectorial scan images. Multiple views may be viewed simultaneously as well to assist with data analysis. This technique is also used in a single-axis scan motion, which makes it more efficient than manual scanning for data collection.

8.10 Hardness Testing

8.10.1 Hardness Testing for PQR and Production Welds

Hardness testing of the base metal, weld, and HAZ is often required to ensure that the welding process, and any PWHT, has resulted in an acceptable relative hardness. Testing production welds and HAZ requires a clean, flat area on the weld and on the base material as close as possible to the toe of the weld to accommodate the hardness testing instrument in the area of interest. The HAZ can be difficult to locate and is often assumed for testing purposes to be just adjacent to the toe of the weld. Hardness testing for a PQR is easier because the coupon is cross-sectioned and etched to identify the weld, weld interface, and HAZ. API 582 details hardness test requirements for PQRs and production welds. High hardness is particularly an issue with hardenable materials where the weld size is small compared to the base metal being welded (i.e. tube-to-tubesheet welds).

Hardness testing of production welds often utilizes portable equipment. Field measurements tend to have greater variability and so additional measurements may be required to verify results. However, hardness testing performed as part of the PQR uses laboratory equipment where significantly greater accuracy is possible. Portable hardness testers are not substitutes for the bench top models, and results from portable testers are prone to error, due to the limited capabilities of such equipment, as well as their improper use.

8.10.2 Hardness Testing for Repair Welds

On-site hardness testing may be required on pressure-retaining welds after any PWHT in accordance with API 582 and NACE SP0472. Hardness testing of repair welds can be conducted with portable hardness testers in accordance with either ASTM A833, ASTM A1038, or ASTM A956

Using API RP 582 as a reference, the HAZ hardness readings may include locations as close as possible (approximately 0.2 mm) to the weld interface (see Figure 57). The surface should be polished and should not exceed 16 µin. (0.4 µm) maximum. After the surface has been polished, it should be etched to identify the weld metal, weld interface, and HAZ.

An example of how hardness measurements may be conducted is shown in Figure 57. Five impressions in an area of approximately 1 in.^{2} (650 mm^2) should constitute a test. Because field hardness measurements tend to have greater variability, additional assessments such as field metallography replication (FMR) can be conducted to determine whether an excessively hard HAZ microstructure has been formed.

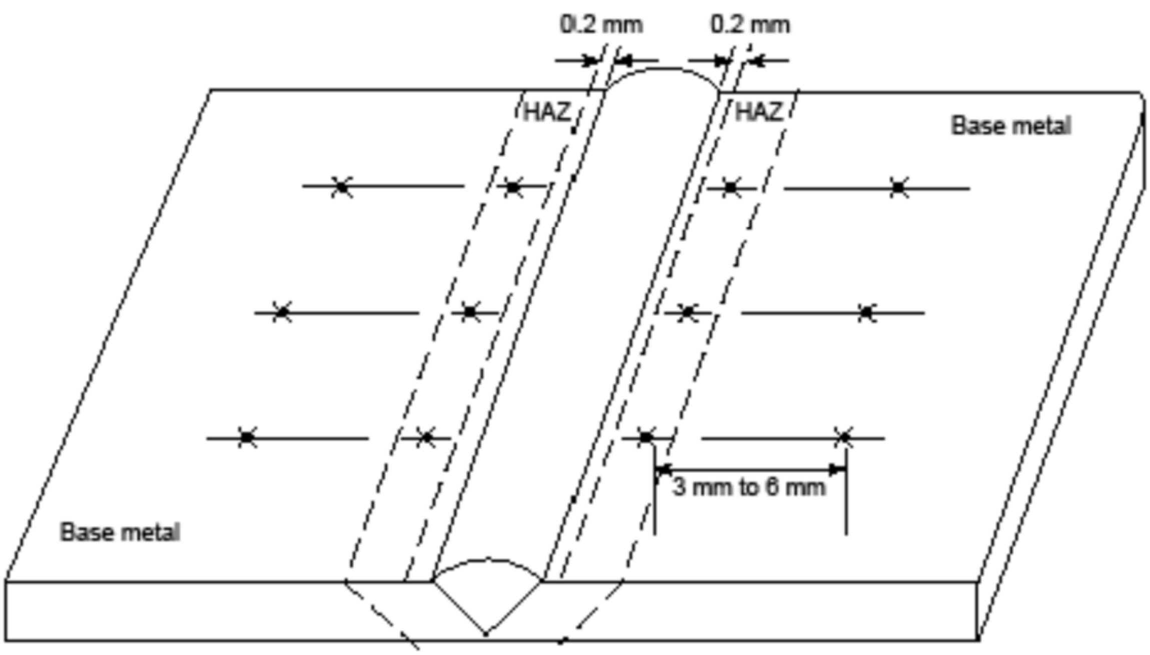


Figure 57—Location of Hardness Measurements

8.11 Pressure and Leak Testing/Examination (LT)

Where a hydrostatic or pneumatic pressure test is required by code, the inspector should adopt code and specification requirements relevant to vessels or piping. API 510, API 570, API 574, ASME B31.3, and ASME PCC-2 provide guidance on the application of pressure tests. Pressure tests should be conducted at temperatures appropriate for the material of construction, above what is known as the minimum design material temperature (MDMT) to avoid brittle fractures.

Some codes and specifications identify the test pressure and duration. Others provide a general direction without a specific set of guidelines. The test should be held long enough for a thorough visual inspection to be completed to identify any potential leaks. Typically, a pressure test should be held for at least 30 min, or as specified by the referencing code or specification. The inspector should be aware of the effect that changing temperature of the test medium has in causing an increase or decrease of pressure during the test period.

Pneumatic pressure tests often require special approvals and additional safety considerations due to the amount of stored energy in the system. Where pneumatic LT is conducted, the inspector should verify safe pressure-relieving devices, and the cordoning off of test areas to exclude all but essential personnel, and the inspector should use extreme caution. Safety professionals should provide the necessary direction to ensure the safety of all personnel in the area.

LT may be required by code or specification to demonstrate system tightness or integrity, or may be performed during a hydrostatic pressure test to demonstrate containment of a sealed unit such as a pressure vessel. ASME Section V, Article 10, addresses LT methods and indicates various test systems to be used for both open and closed units, based upon the desired test sensitivity. LT of a welded tube-to-tubesheet joint may be specified for service applications that are sensitive to small tube-to-tubesheet joint leaks. Helium LT is especially effective for tube-to-tubesheet joints when highly sensitive LT is required.

NOTE LT is not the same as, nor is it a substitute for, hydrostatic or pneumatic testing.

One of the most common methods used during pneumatic LT is the direct pressure bubble test. This method employs a liquid bubble solution that is applied to the areas of a closed system under pressure. A visual test is then performed to note any bubbles that are formed as the leakage gas passes through it. When performing the bubble test, some items of concern include the temperature of the surface to be inspected, pretest and posttest cleaning of the part to be inspected, lighting, visual aids, and the hold time at a specific pressure prior to application of the bubble solution. Typically, the area under test is found to be acceptable when no continuous bubble formation is observed. If the unit under pressure is found to have leakage, it should be depressurized, the leaks repaired per the governing code, and the test repeated.

A wide variety of viscous fluids and methods can be used, dependent on the desired result. Considerations for system design limitations may prevent the use of water (the most common type of leak test). Drying, hydrostatic head, and support limitations should be addressed before water is used. The required sensitivity of the results may also require a more sensitive leak test medium and method.

NOTE Publications on pressure testing safety are available from several sources, including (but not limited to) Interstate Natural Gas Association of America (INGAA), Health and Safety Executive (HSE), and Mechanical Contractors Association of America (MCAA). These are not the only sources on the subject. Information on them is included in the bibliography.

9 Welding Inspection

9.1 General

Weld inspection is a critical part of an overall weld quality assurance program. Welding inspection includes much more than just the NDE of a partially completed or completed weld. Important issues prior to welding include review of codes, standards, specifications, design, cleaning procedures, welding procedures, and welder qualifications.

Welding inspection activities can be separated into three primary stages corresponding to the phase of the welding work process. Inspectors should perform specific tasks prior to welding, during welding, and upon completion of welding. Codes, standards, and specifications will dictate the amount of inspection that is to be performed. Along with performing the required inspections, complete and accurate documentation shall be generated. In almost every case, the documentation alone will serve as proof that the required inspections were performed in accordance with codes, standards, specifications, and regulatory requirements.

9.2 Tasks Prior to Welding

The importance of tasks in the planning and weld preparation stage should not be understated. Many welding problems can be avoided during this stage when it is easier to make changes and corrections, rather than during or after the welding is in progress or has been completed. Such tasks may include the following.

9.2.1 Drawings, Codes, and Standards

Review applicable drawings along with standards, codes, internal specifications, and all welding documentation, including the WPS, PQR, and WPQ, in order to understand the requirements for the weldment and identify any inconsistencies.

9.2.1.1 Quality Control Items to Assess

Items that should be reviewed in drawings, codes, and standards include the following.

a) Welding symbols and weld sizes are clearly specified (see Annex A). Note that welding symbols are often not included in plans for in-service welding and repairs.

b) Weld joint designs and dimensions are clearly specified (see Annex A).

c) Dimensions are detailed—the inspector may need to seek help from others (e.g., welding engineer) to determine potential for distortion.

d) Welding consumables are specified.

e) Proper handling of consumables, if any, is identified.

f) Base material requirements are specified (such as the use of impact tested materials where notch ductility is a requirement in low-temperature service).

g) Mechanical properties and required testing are identified on the PQR.

h) Weather protection and wind-break requirements are defined in the referencing code or standard.

i) Preheat requirements and acceptable preheat methods are defined.

j) PWHT requirements and acceptable PWHT methods are defined.

k) Inspection hold-points and NDE requirements are defined.

l) Additional requirements, such as production weld coupons, are clearly specified.

m) Pressure testing requirements, if any, are clearly specified.

n) Appropriate type/degree of NDE is specified.

o) WPS and corresponding PQR for essential, nonessential, and, if applicable, supplementary variables have been reviewed and addressed.

p) WPQ has been reviewed to ensure proper testing was performed to allow the welder to produce a production weld according to the relevant WPS.

9.2.2 Welding Requirements

Review requirements for the welding personnel involved with executing the work, such as the welding organization and inspection organization.

9.2.2.1 Quality Control Items to Assess

Welding requirement quality control items that should be reviewed are as follows.