

Ultrasonic Inspection

PART OF THE CWB CERTIFICATE PROGRAMS



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MODULE 19

**ULTRASONIC
INSPECTION****CONTENTS**

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MODULE 19

ULTRASONIC INSPECTION

Introduction

Visual inspection, although often the most effective means of inspecting a welded structure, is limited to examination of the surface of welds. In many situations a *volumetric* inspection is required that is capable of detecting internal defects within a weld. The most widely used volumetric nondestructive examination methods are radiography (radiographic testing, RT) which was discussed in Module 18 and ultrasonics (ultrasonic testing, UT) which is covered in this module.

Ultrasonic testing requires a high degree of operator skill and is carried out by trained and certified technicians. But the inspector must have sufficient knowledge to verify that code requirements are followed, and that procedures are properly executed.

It is the objective of this module to cover ultrasonic testing as applied to welds so that after successfully completing this module you should be able to:

Objectives

- Describe the basic principles of the ultrasonic test method
- List the advantages and limitations of ultrasonic testing
- Discuss the calibration of equipment and the suitability of equipment and materials for the specification for ultrasonic testing
- Describe various techniques for inspecting welds
- Describe ultrasonic testing procedures
- Describe the typical code requirements governing ultrasonic testing
- List the critical parameters in an ultrasonic test report

PRINCIPLES OF ULTRASONIC TESTING

Sound, as a method of testing products, has been used for many years, an early application being the familiar tapping of railway wheels (Fig. 1). Today, ultrasonic testing has evolved into one of the most sophisticated and technically advanced nondestructive examination methods. Ultrasonic principles are also used in range finders, proximity sensing, and thickness testing.

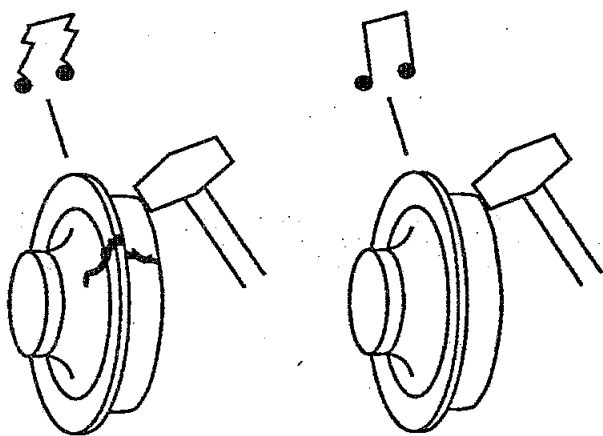


Figure 1. Hammer test of railway wheel, early application of sound in product testing.

Most ultrasonic flaw detection in welds is done by moving a small probe over the surface of the plate adjacent to the weld by hand and watching a display on an oscilloscope screen (Fig. 2). The probe must be coupled to the surface of the metal by a layer of liquid (typically water, oil, or glycerine). The probe produces a beam of ultrasound which passes into the metal and is reflected back from any discontinuity in the weld as an echo. To understand how the method works we must first discuss some of the physical principles involved.

Sound waves are mechanical vibrations which are detectable by the ear. Vibrations have a characteristic frequency, i.e., number of vibrations per second. Sound of a very high frequency (above the range which can be detected with the human ear) is called ultrasonic (Fig. 3).

Sound

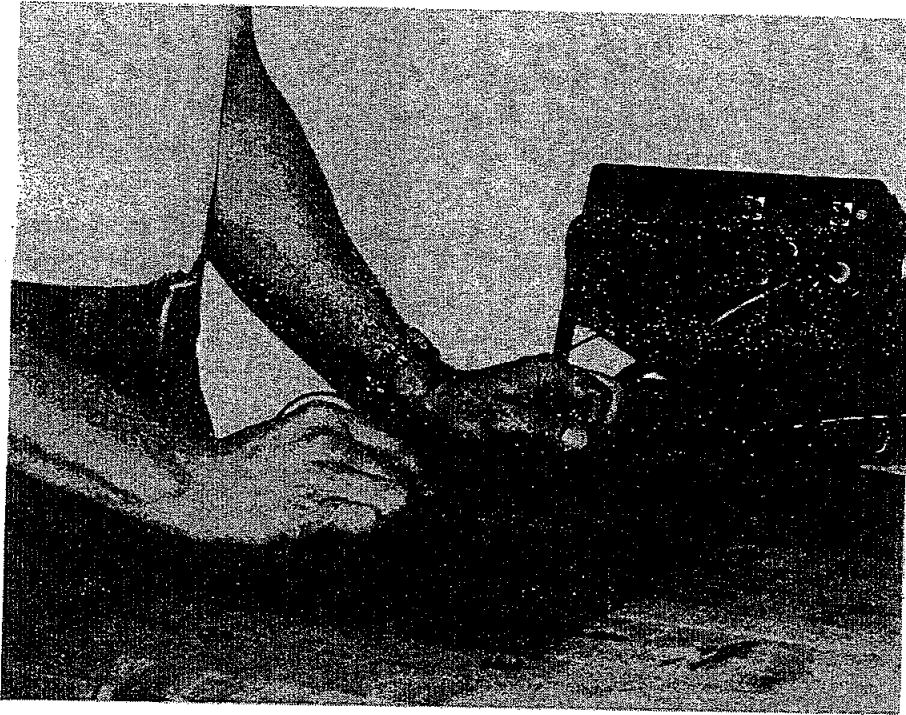
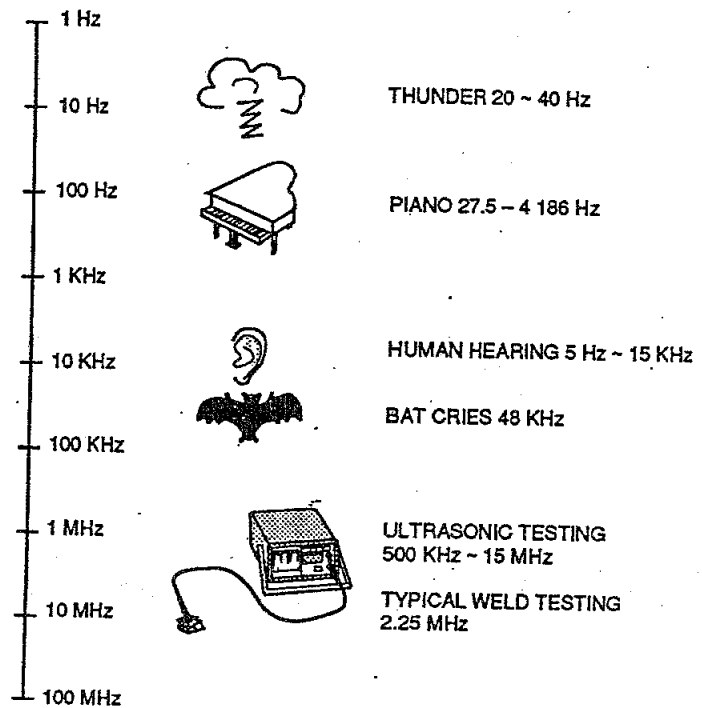


Figure 2. Ultrasonic testing of a weld.

Figure 3. Sound spectrum showing examples for various frequency ranges. Ultrasonic frequencies are very high, beyond the range of human hearing.



Sound waves

Wavelength

A wave is a disturbance that moves through a material by the transfer of energy from one particle to another. Characteristics of the wave which depend on the mechanical properties of the material are the wavelength, the wave velocity, and the frequency.

Wave length is the shortest distance between two particles in a wave which are moving in the same direction, at the same velocity, and at the same time (in phase) as illustrated in Fig. 4. For example, the wavelength is the distance between the crests of the waves.

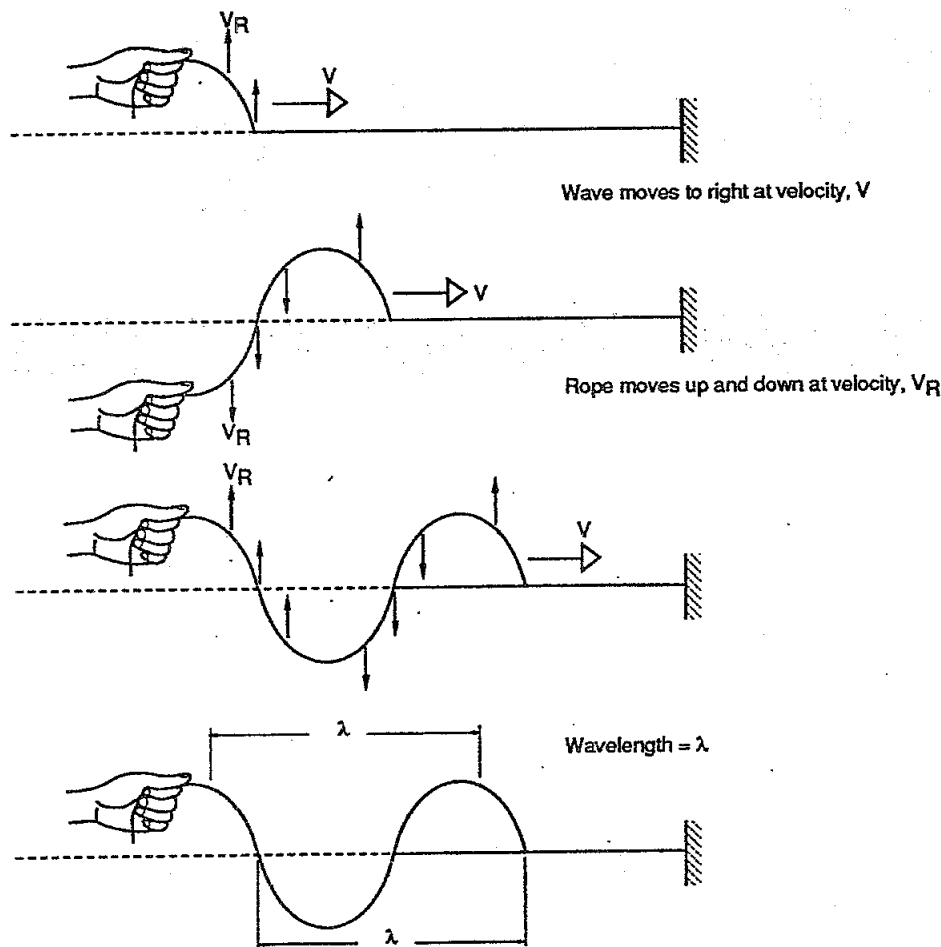


Figure 4. Induced wave in a length of rope.

Velocity frequency relationship

Velocity, wavelength, and frequency are related according to a fundamental wave equation.

$$\text{Velocity} = \text{Wavelength} \times \text{Frequency}$$

$$V = \lambda f$$

$$V = \text{Velocity, m/s}$$

$$\lambda = \text{Wavelength, m}$$

$$f = \text{Frequency, Hz (unit of frequency is the Hertz which is the number of cycles per second and has the dimensions sec}^{-1}\text{)}$$

For example a typical ultrasonic wave in steel:

$$\text{Steel } V = 5.85 \times 10^3 \text{ m/s}$$

$$\text{Frequency } f = 2.25 \text{ MHz (2 250 000 cycles/s)}$$

$$\text{Wavelength } \lambda = \frac{V}{f} = \frac{5.85 \times 10^3 \text{ m/s}}{2.25 \times 10^6 \text{ cycles/s}}$$

$$= 2.6 \times 10^{-3} \text{ m} = 2.6 \text{ mm}$$

The velocity of ultrasound in a material depends on the mechanical properties of that material—its modulus of elasticity, Poisson's ratio, and its density. Velocities of ultrasonic waves in some typical materials are shown in Table 1. Note that if a wave of a given frequency travels through different materials with different velocities, the wavelength will be different in each of the materials.

Table 1. Typical ultrasonic wave velocities in different materials, m/s. Values for two different types of waves are given.

Material	Compressional or longitudinal waves	Shear or transverse waves
Steel	5.85×10^3	3.2×10^3
Aluminum	6.26×10^3	3.1×10^3
Water (20°C)	1.5×10^3	—
Perspex	2.7×10^3	1.1×10^3
Oil	1.2×10^3	—

Amplitude and power

The height of a wave (i.e., the maximum displacement of a particle) is the amplitude, A (see Fig. 5). The energy carried by a wave depends on the amplitude and on the frequency, f :

$$E \propto (Af)^2$$

Changes in energy are measured on a logarithmic scale in units of *bels* or *decibels*. These are defined as:

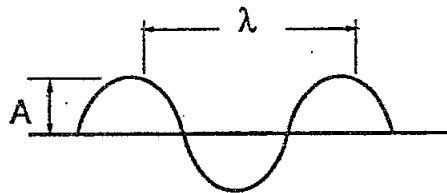
$$\text{energy change in bels} = \log E_1 - \log E_2 = \log \frac{E_1}{E_2}$$

$$\text{energy in decibels} = 10 \times \log \frac{E_1}{E_2}$$

Note that since energy is proportional to the square of the amplitude, the decibel change can be written:

$$\begin{aligned} \text{change in decibels} &= 10 \times \log \frac{A_1^2}{A_2^2} = 10 \times \log \left(\frac{A_1}{A_2} \right)^2 \\ &= 20 \times \log \frac{A_1}{A_2} \end{aligned}$$

As an example, doubling the amplitude is an increase of 6 dB. A 20 dB increase represents 10 times the amplitude. The decibel change is the method used for measuring intensities of ultrasonic waves.



$$V = \lambda f$$

Figure 5. Terminology for a wave.

Attenuation

As an ultrasonic wave travels through a material, it gradually loses energy from beam spread, absorption and scattering. This is known as attenuation. It means that the magnitude of the echo from a reflector depends on the distance the wave must travel through the material

before being reflected back (Fig. 6). The degree of attenuation increases with the frequency. It also depends on the type of material, grain size, and so forth. For a given material there is a steady rate of attenuation (except for the 'near field' where the wave enters the material) which can be established by tests. Such information may be needed in order to make a 'distance-amplitude correction' (DAC) to the amplitude of a reflection and will be discussed more fully in a later section.

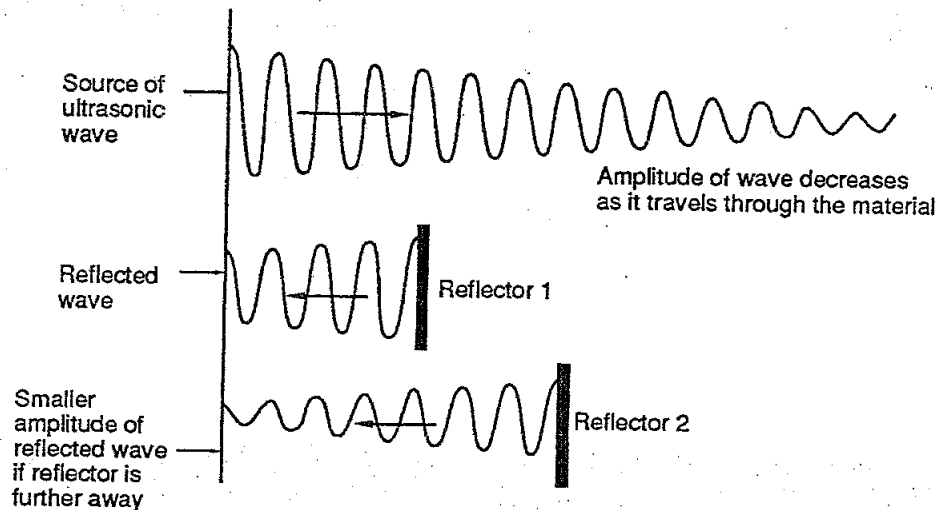


Figure 6. Ultrasonic waves lose energy as they travel through a material thus producing smaller echoes from reflectors further away.

Transducer

Mechanical vibrations used in ultrasonic examination are generated by electromechanical transducers, devices which are able to transform electrical energy into mechanical energy, and vice versa. For the frequencies used in ultrasonic examination of welds, piezoelectric transducers are used.

KNOW THIS

Piezoelectric crystals change shape when an electrical potential is applied to them. Thus by applying a voltage a crystal can be made to vibrate and generate an ultrasonic wave in any material it contacts (Fig. 7). Conversely, a mechanical vibration applied to a piezoelectric crystal will generate a small electric voltage. Thus the crystal can be used to both generate and to detect ultrasonic waves.

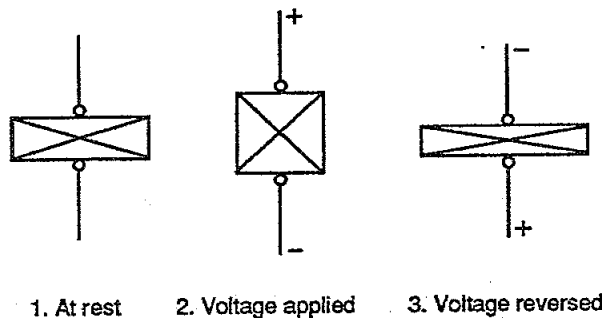


Figure 7. Piezoelectric effect: applied voltage causes shape change.

A transducer is most effective at its own natural resonant frequency, i.e., the frequency at which it will vibrate after a single mechanical or electrical stimulus. A natural frequency is a direct function of thickness and thus the thickness of the transducer is carefully selected to produce a standard test frequency.

Table 2. Some typical transducer thicknesses.

Material	1 MHz	5 MHz	10 MHz
Quartz	2.86 mm	0.572 mm	0.286 mm
Lithium sulphate	2.54 mm	0.508 mm	0.254 mm

Quartz is a natural piezoelectric material although other materials, such as lead metaniobate, are now more commonly used. Table 2 shows some typical transducer thicknesses. To protect the very thin and delicate transducer, it is mounted in a package called a probe, search unit, or transducer assembly. Fig. 8 shows the cross-section of a typical probe.

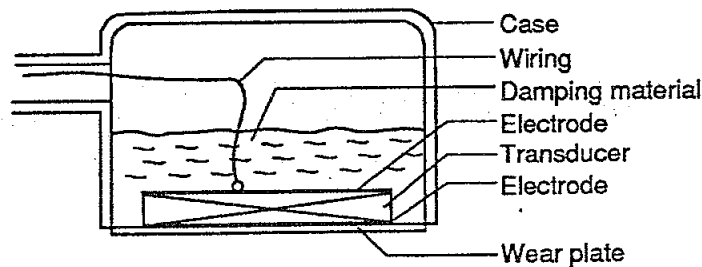


Figure 8. Cross-section of a typical probe.

Pulses of sound

For special applications electromagnetic acoustic transducers (EMATs) have recently been developed. These have the advantage that direct contact is not required but because of their low power they are not in wide use.

When the transducer is excited by subjecting it to a voltage across its thickness it contracts or expands. The transducer then vibrates for a short period at its natural frequency, producing a wave train of a length determined by the material and mechanics of the transducer.

The short burst of mechanical energy travels into the specimen until it is reflected by a plane surface. If the reflecting surface is 90° to the beam it returns to the contact surface where the transducer is now sitting passively. When the vibration hits the transducer, it is once again translated into an electrical pulse.

This is the pulse-echo principle. The transducer may act as both transmitter and receiver or two separate transducers, chosen for acoustic properties, may be used (Fig. 9).

Couplant

KNOW THIS

Ultrasonic waves for weld inspection have too high a frequency to travel in air so to transfer energy across the interface between the transducer and the test specimen it is necessary to use a *couplant* which eliminates air gaps. Typical couplants are oil, water and glycerine. Couplants are discussed more fully in the sidebar.

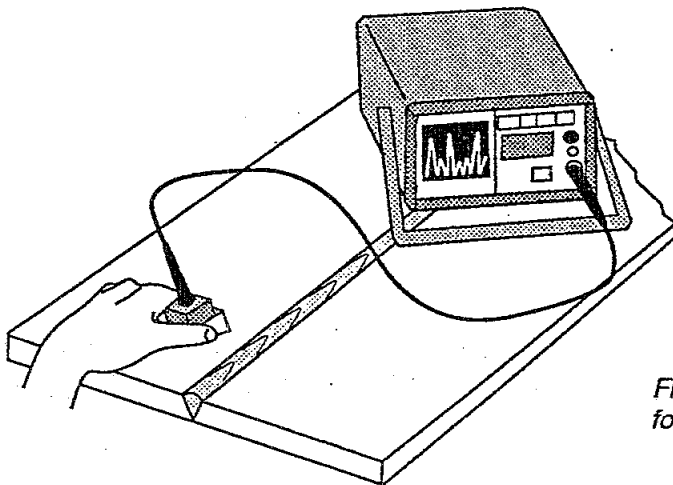


Figure 9. The pulse-echo method for ultrasonic testing.

Couplants

KNOW PROPERTIES

COUPLANTS. A contact test cannot be successful without a suitable couplant between the search unit and material. The couplant may be almost any material, liquid, semi-liquid, or paste, which:

- Wets both the surface of the test material and the face of the search unit, excluding air between them.
- Is easily applied.
- Does not run off the surface too fast.
- Is homogeneous and free from bubbles or solid particles which would reflect and scatter the beam.
- Is not corrosive or toxic.
- Has an acoustic impedance approaching that of the test material. (This is an ideal rather than a restrictive requirement.)
- Must be easily removed when welding is carried out after UT.

Selection of Couplants. The following examples illustrate how a suitable couplant may be selected:

- Water is suitable but should have a wetting agent added. It is often too low in viscosity to stay on the test surface long enough to complete the test.
- Various grades of oil are used more frequently because they stay on the test surface longer. Oils containing wetting agents (as do many commercial oils) are desirable.
- Heavier oils and greases are used on hot or vertical surfaces and to fill surface irregularities on very rough surfaces, because they stay in place.
- One part of glycerine in two parts of water with a wetting agent is often used because it adheres more effectively to surfaces and is an excellent couplant.



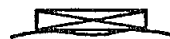
Dry, Honed
Good transmission



Dry, Smooth
Poor transmission



Smooth *plus* couplant
Good transmission



Rough *plus* couplant
Poor transmission

Effect of surface finish and couplant on sound transmission.

Ultrasonic testing circuit

ULTRASONIC EQUIPMENT

Information during ultrasonic testing is presented in a visual display, most commonly on a cathode ray tube (CRT). In order to create a stationary display the ultrasonic pulses are transmitted at a constant rate in the range from about 30 to more than 1 000 pulses per second. In order to synchronize the CRT display with the transmission of pulses the circuit includes a timebase which controls both the CRT sweep rate and the pulse generator.

Signals received from reflections produce a very small voltage in the transducer and must be amplified before reading the display. The basic elements of a typical circuit for ultrasonic testing are shown in Fig. 10.

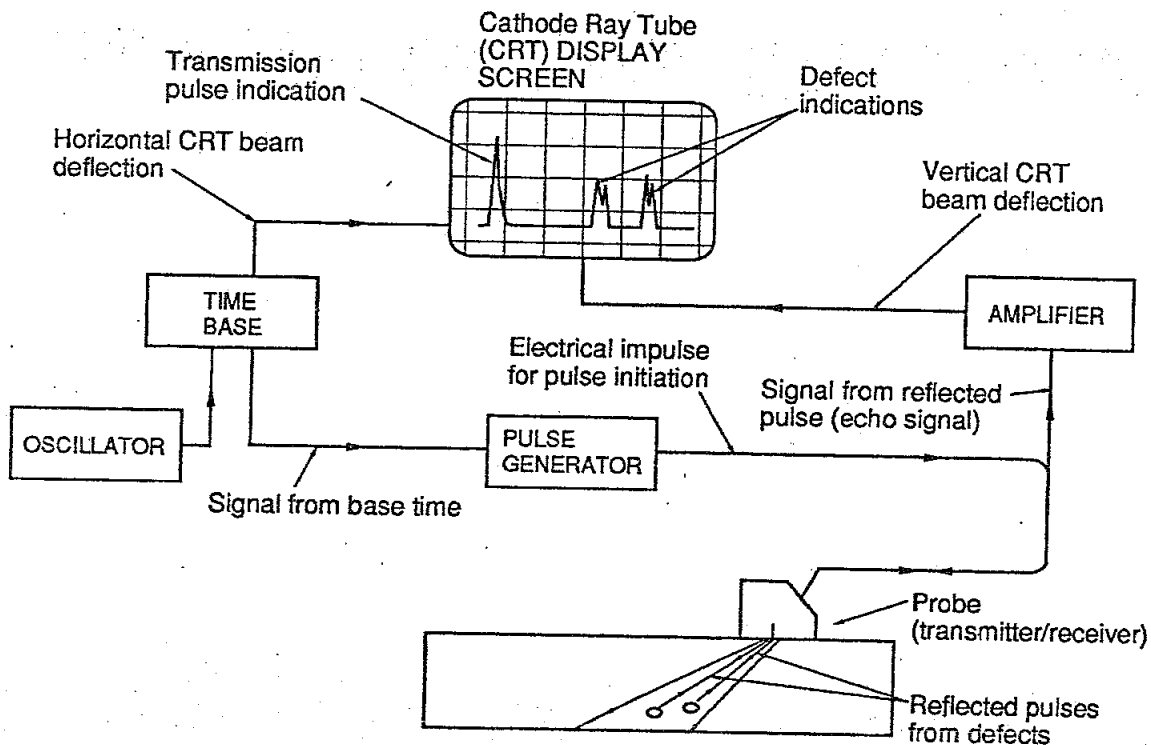


Figure 10. Block diagram of basic ultrasonic pulse-echo equipment.

Displays A-scan

There are several ways in which ultrasonic information can be displayed and advances in computer-based imaging technology has made some sophisticated image display methods available. However, the vast majority of commercial applications uses the simple display method known as A-scan.

In A-scan the CRT simply traces a graph of signal amplitude versus time. The timebase sweeps the CRT beam across the screen in the horizontal direction while the ultrasonic signal causes vertical deflection. The initial pulse appears at the left of the screen and if a discontinuity is present a reflected signal arrives back at the transducer sometime later, appearing on the screen displaced to the right (Fig. 11). Since the time between the transmitted and reflected pulses is proportional to the distance from the probe (transmitter) to the reflector, the horizontal scale of the CRT may be calibrated as distance.

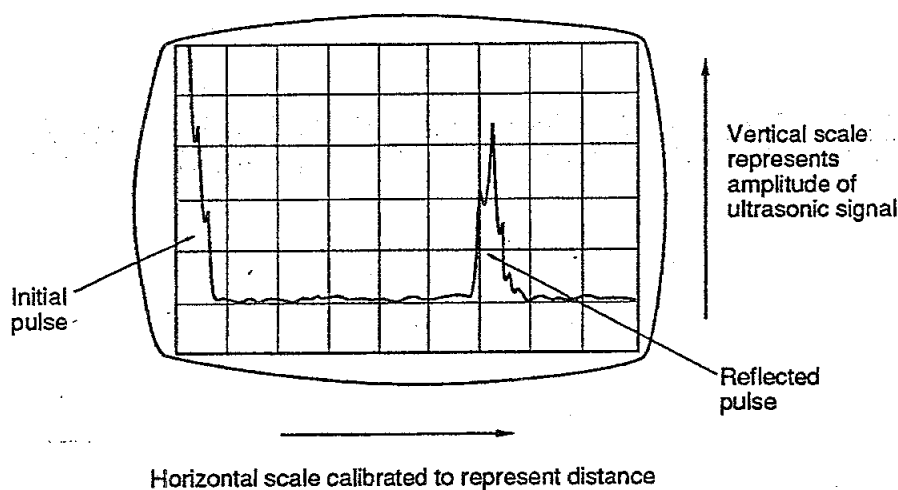


Figure 11. Display using A-scan.

The base of the screen has two key adjustments: delay and scale expansion. The scale expansion permits setting the timebase to represent any convenient distance. It is typical to have scale markings on the face of the screen and to line up indications from a known reflector so that these markings represent a specific distance, say 1 cm. Very small distances can be spread completely across the screen.

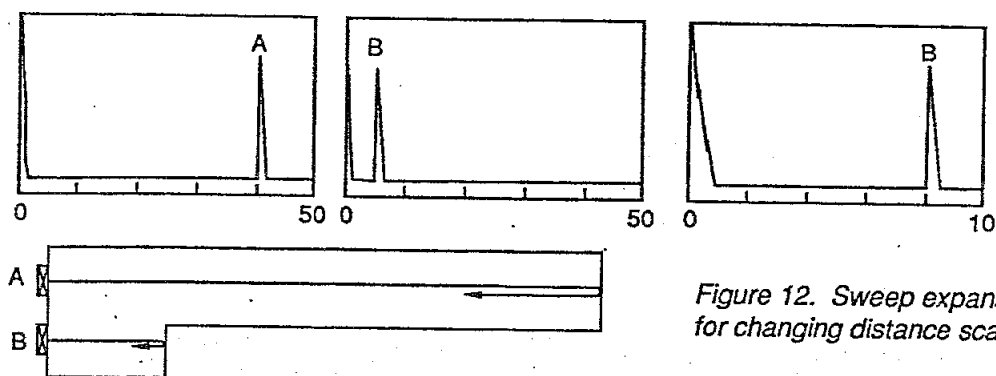


Figure 12. Sweep expansion control for changing distance scale ranges.

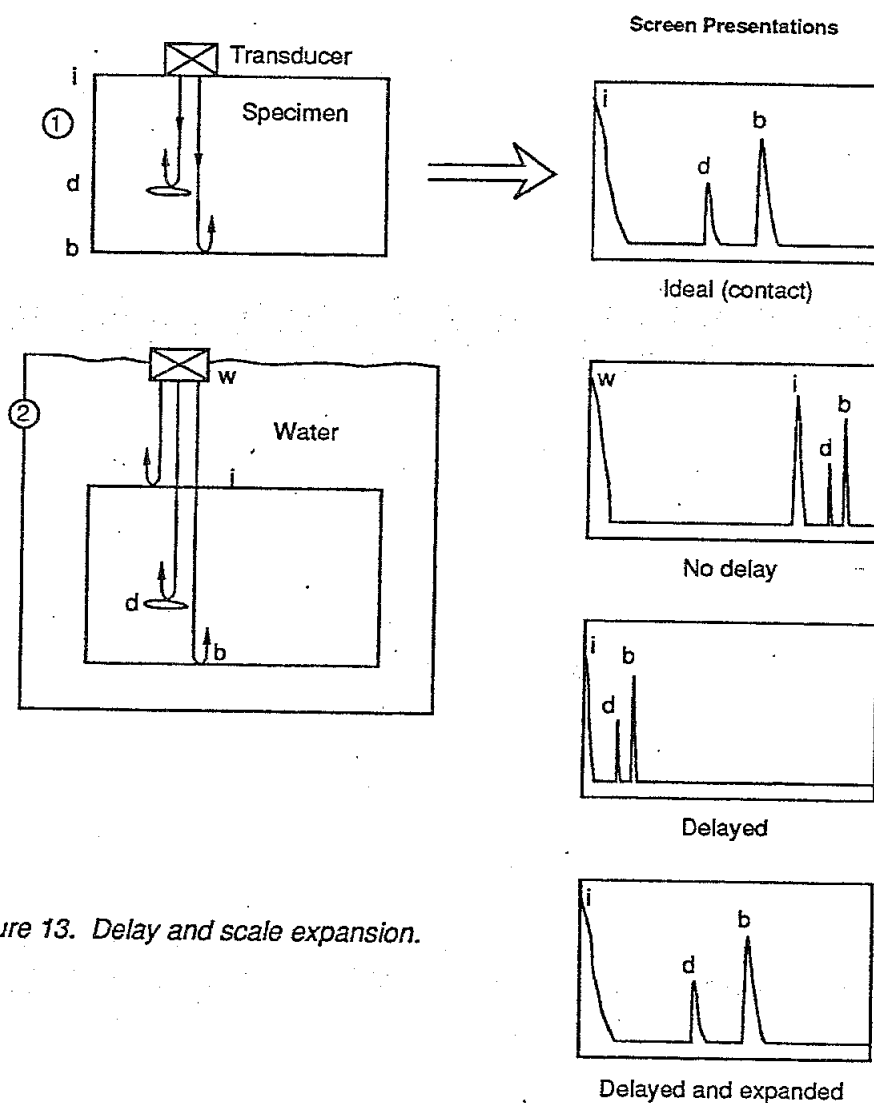


Figure 13. Delay and scale expansion.

While it is most common to have the pulse which represents the entry surface on the left of the screen as a reference point, in some circumstances this may not be desirable. The delay control allows the operator to select the initial depth within the specimen that is represented on the screen. Fig. 12 illustrates scale expansion and Fig. 13 delay and scale expansion.

Note that the pulse must have a finite duration and that reflected pulses cannot be detected until the transmitted pulse dies away. There is therefore a dead zone close to the transducer in which discontinuities cannot be detected. This makes it difficult for UT to find defects close to the surface or for the inspection of thin materials.

The height on the screen representing the amplitude of the signal can be adjusted by a gain control which is calibrated in decibels. Thus to double the height of an indication on the screen the gain control must be turned through 6 dB (see Fig. 14).

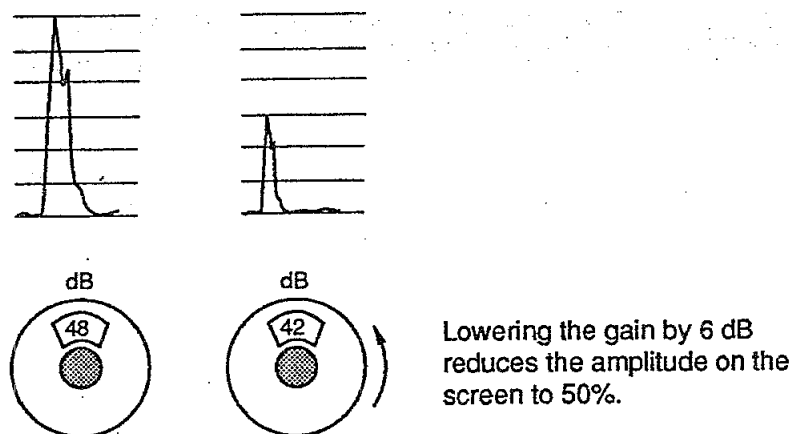


Figure 14. Calibrated gain control for adjusting display height.

Gates

Circuits may also include preset control points that will present a warning if reflectors are detected within a specific distance range or that exceed a specific intensity. For areas such as those shown in Fig. 15 it is customary to flash or sound warnings if signals are received within the limits shown. Limits such as these are called gates.

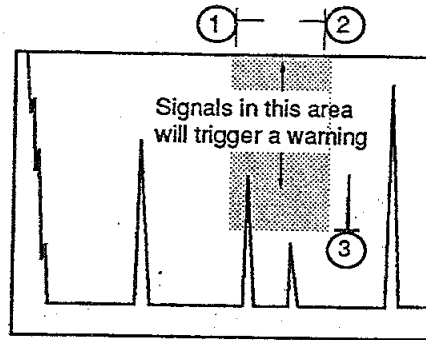


Figure 15. Gates for warning about reflectors between distances 1 and 2 and in specific areas which exceed the set intensity 3.

Distance Gates 1, 2
Intensity Gate 3

Other display methods

If probe position information is added to the ultrasonic signal information previously discussed, such as time (distance) and amplitude, then other display methods are possible.

B-scan display provides a cross-sectional view of the piece being tested as illustrated in Fig. 16. This type of display allows the length and depth of discontinuities to be seen. C-scan display (Fig. 17) provides a plan view thus revealing the size and shape of discontinuities but not their depth. P-scan (projection image scanning) is an advanced 3D imaging system that provides three views of the specimen: top, end, and side. This facilitates visualization allowing for rapid identification of defects (Fig. 18). All of these display techniques require automatic scanning by the probe.

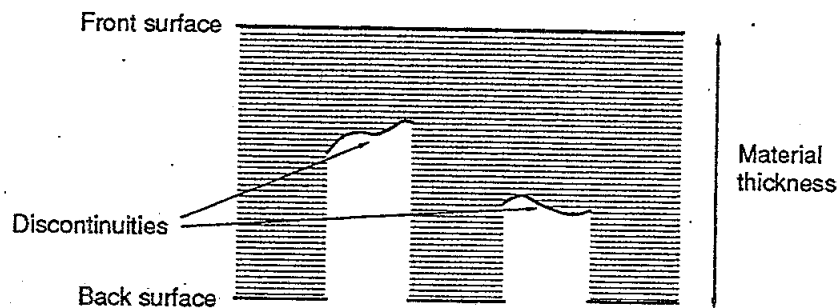


Figure 16. B-scan display.

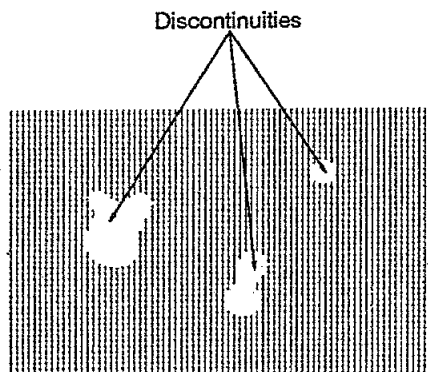


Figure 17. C-scan display.

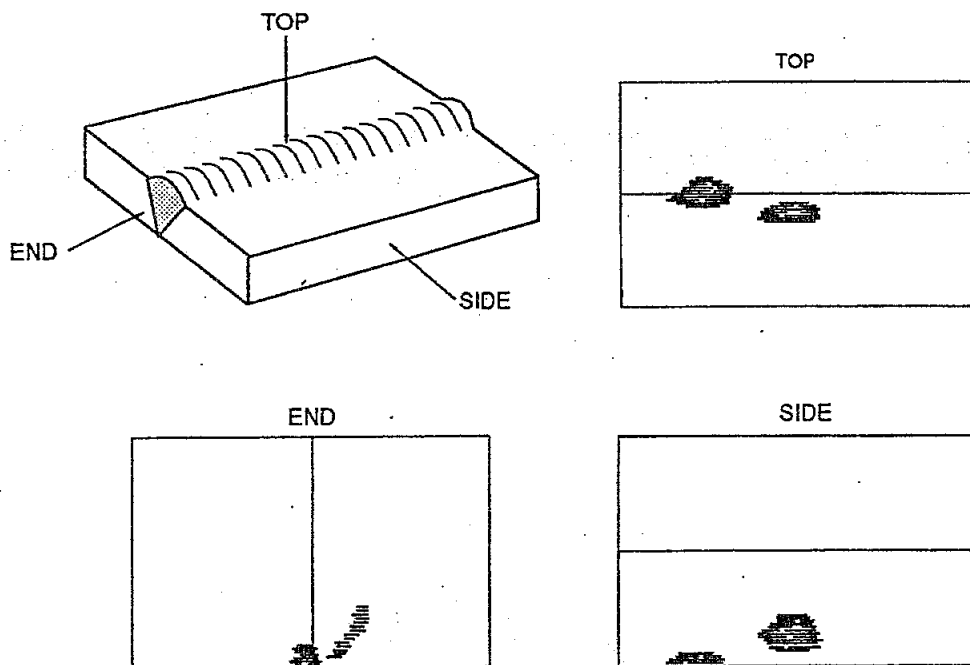
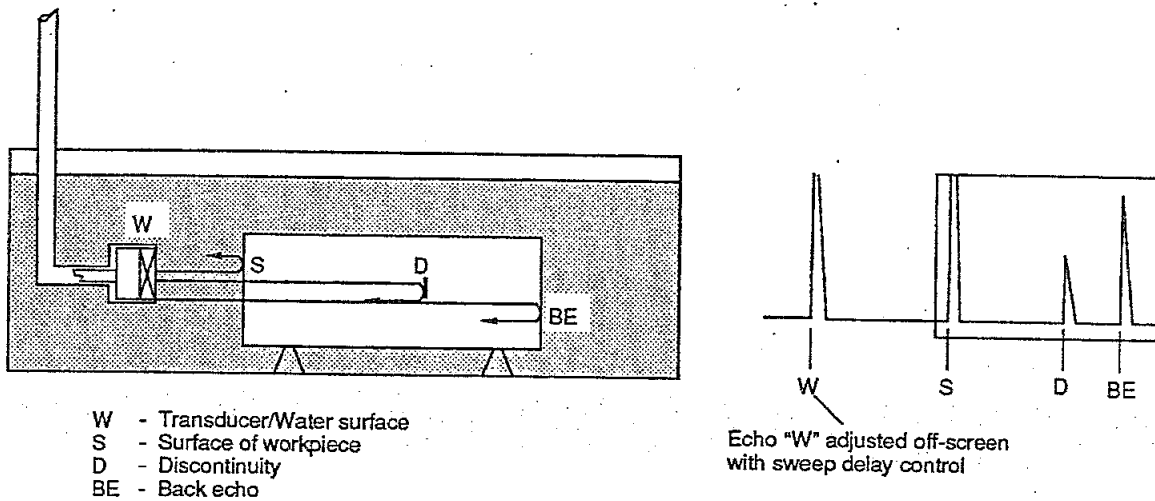


Figure 18. Example of P-scan display (normally in colour) showing easy visualization of discontinuities. The example shows lack of fusion in the side wall and root (end view). The side and top views show the location and size.

A few examples of special systems used in ultrasonic testing are given here. The first is immersion testing where the specimen is completely immersed in water which also acts as the couplant. This system is used when the probe cannot be in direct contact with the specimen (Fig. 19). An example is the automatic, on-line testing of plate. Another example of water coupling is shown in Fig. 20 where a "shoe" containing the probe and filled with water moves over the specimen.



(*) Figure 19. Arrangement for immersion testing. WILL BE TEST QUESTION.

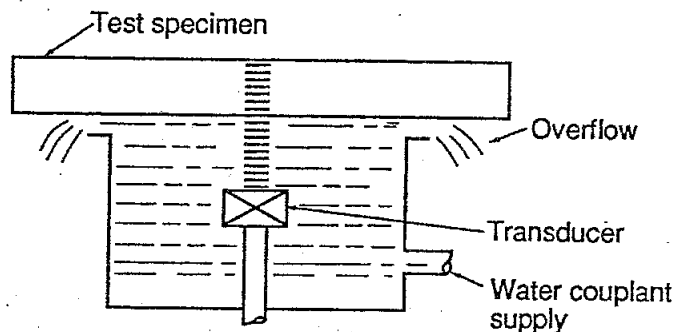


Figure 20. Movable shoe using water coupling.

Principles of acoustic emission

There has been a great deal of research directed to the automation of the ultrasonic test, to eliminate the variables introduced by the operator, to increase speed of inspection, and to take advantage of the capabilities of computerized instrumentation. Computerization also allows for storage of ultrasonic data.

Another NDT method closely related to ultrasonic testing is acoustic emission (AE). Rather than inject an ultrasonic wave into a material and measure the reflections, acoustic emission relies on detecting very small amounts of mechanical energy released from such things as growing cracks or structural discontinuities under load. It may be possible to identify the source of energy from the characteristics of the emission. It may also be possible to determine the location of the source by using several detectors and applying computerized triangulation techniques.

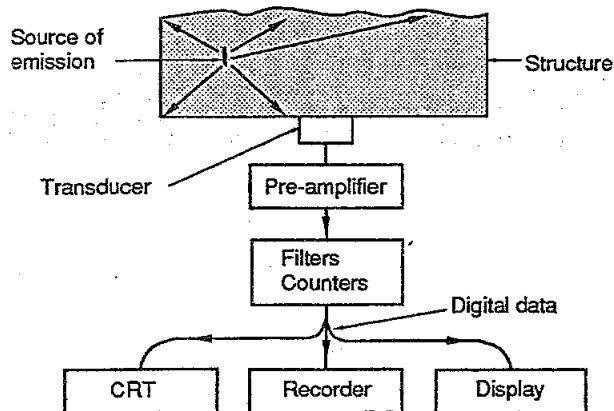


Figure 21. Block diagram of acoustic emission (AE) equipment.

Wave modes

These features make AE a potentially useful system for monitoring, both during welding or global monitoring the service life. Acoustic emission equipment procedures are covered by ASTM E749. Fig. 21 shows the block diagram of acoustic emission equipment.

Ultrasonic waves are classified according to the mode of particle displacement. The two main types are longitudinal (or compressional) waves and transverse (or shear) waves. There are other types such as surface (or Rayleigh) waves but their use for weld inspection is less common and will not be discussed in this module.

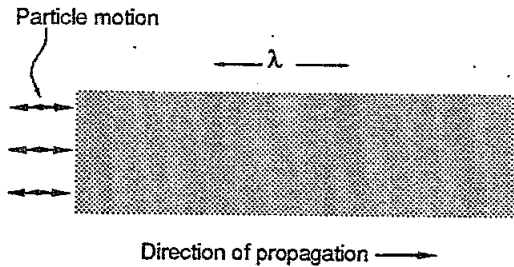


Figure 22. Longitudinal wave.

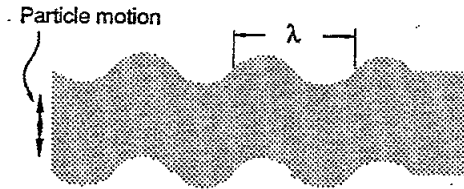


Figure 23. Transverse wave.
ALSO CALLED SHEAR

T.Q.

WHAT TYPES OF WAVES

In the longitudinal mode, the energy is carried by particles moving back and forth in the same direction as the movement of the wave (Fig. 22). In the transverse mode, the particles move back and forth at right angles to the direction in which the wave is moving (Fig. 23). Transverse waves can only be carried in a solid. Each type of wave travels at its own characteristic speed in a specific material, related to the mechanical properties of that material. Typical velocities for the two types of waves were shown in Table 1.

Mode conversion

When an ultrasonic beam is incident at an angle other than a right angle to the interface between two materials having unequal sound velocities, the transmitted beam will have a new direction of propagation, determined by the angle of refraction. Additional beams may be generated by mode conversion.

Snell's Law

The angular relationship is given by a law of optics; Snell's Law:

$$\frac{\sin \phi_1}{V_1} \equiv \frac{\sin \phi_2}{V_2} \equiv \frac{\sin \phi_3}{V_3}$$

where ϕ_n is the angle of incidence and V_n is the velocity in medium n.

Since the longitudinal wave travels at a higher velocity in a given material than the transverse wave, it follows that the angle of refraction of the longitudinal beam is larger than that of the transverse beam as shown in Fig. 24.

Critical angles

In Fig. 24, as the angle of incidence (ϕ_1) is increased, the two angles of refraction (ϕ_2 and ϕ_3), also increase. The angle of incidence at which the refracted longitudinal beam is parallel to the surface is called the *first critical angle*. If the angle of incidence is just greater than the first

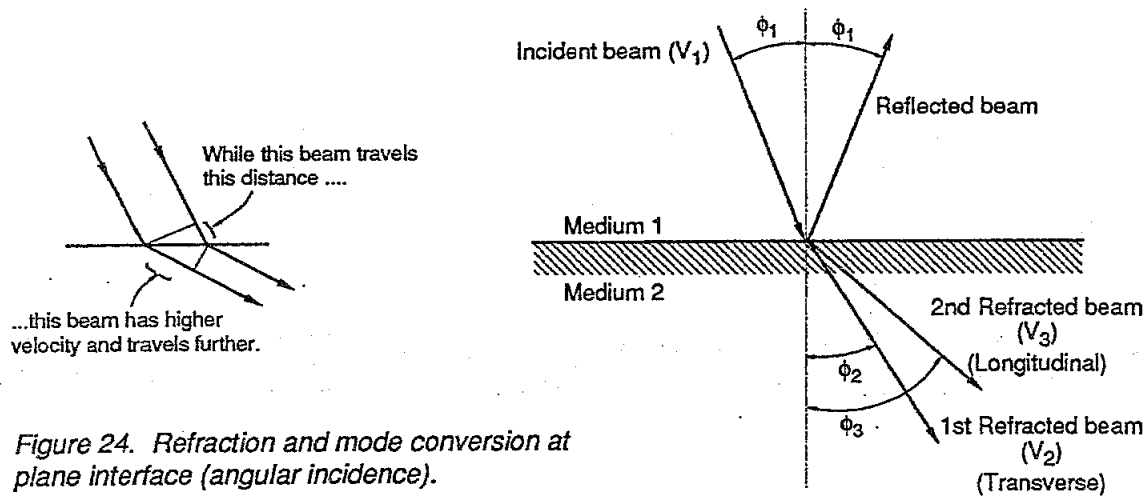


Figure 24. Refraction and mode conversion at plane interface (angular incidence).

critical angle, the longitudinal wave component within the bulk of the material is eliminated and only the transverse wave remains. This is of importance because beams other than the one being used for inspection can cause reflections which make interpretation difficult.

A *second critical angle* occurs when the refracted angle of the transverse beam (ϕ_2) is 90 degrees. At this angle, all of the energy transmitted across the interface travels along the surface of the test specimen.

Most ultrasonic inspection of welds employs transverse waves, and thus incident angles are chosen such that the refracted angle lies between the first and the second critical angle. Probes are designed to produce a transverse wave at a specific angle. The transducer first generates a longitudinal wave in a plastic block. This changes velocity as it enters the material and therefore refracts (Fig. 25). The angle of incidence in the plastic is carefully chosen to give the required refracted

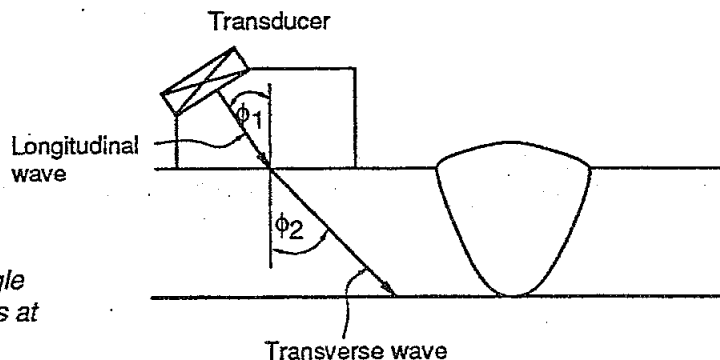


Figure 25. Construction of an angle probe producing transverse waves at a specific angle.

Sensitivity

angle in the material under test. The exact angle of the probe should be found by calibration. Note that the angle of a probe is only valid for one material. For example, 70°—steel.

Sensitivity is the ability of the ultrasonic testing system to detect small reflectors. It is directly related to wavelength. The shorter the wavelength (and higher the frequency), the more sensitive the system.

Example:

For a 5 MHz longitudinal wave in steel, the wavelength is

$$\lambda = \frac{V}{f} = \frac{5.9 \times 10^3 \text{ m/s}}{5 \times 10^6 \text{ Hz}} = 1.18 \times 10^{-3} \text{ m} = 1.18 \text{ mm}$$

As a general rule, the size of reflector that may be detected is in the order of 1 wavelength. However, the degree of interference through reflection and scattering will increase as wavelength gets shorter. In general, the test should use the lowest frequency practical to detect the anticipated size of defect.

Resolution

Resolution refers to the ability of the ultrasonic test system to distinguish between two closely spaced reflectors, and to resolve discontinuities close to the test surface. If the discontinuities are close

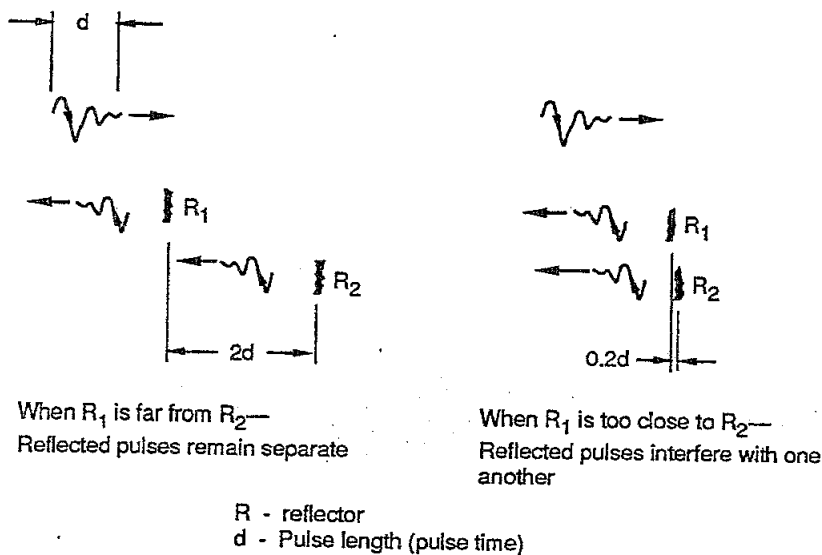


Figure 26. The resolution limit of an ultrasonic testing system.

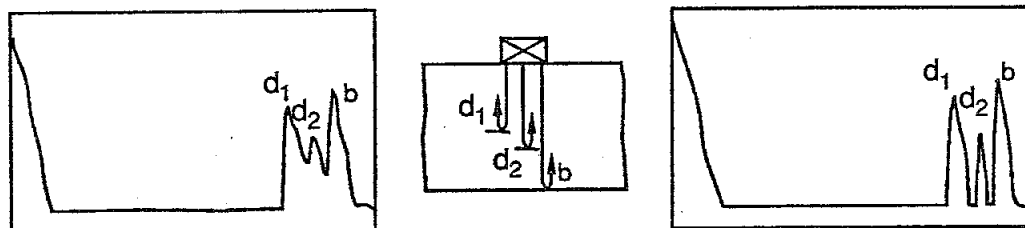


Figure 27. Examples of poor (left) and good (right) resolution.

Beam spread

together the reflected pulse from one interferes with the other (see Fig. 26 and Fig. 27).

The spread of the beam in the material is related to the size of the transducer and to the ratio of the wavelength and size. The smaller the transducer the more it would behave like a small point from which sound would emanate in all directions. As the transducer gets larger, the waves coming from it become flatter and more like plane waves which have zero beam spread. When the ratio between the wavelength and the transducer diameter is small, it promotes a straight penetrating beam. Beam spread will therefore be less for large transducers and for higher frequencies. See Fig. 28.

The beam may be thought of as a cone with the highest intensity along its axis. Away from the axis the intensity drops off giving the beam its profile which can be measured. For an angle probe the beam axis can be considered to emanate from a specific point on the probe, termed the exit point.

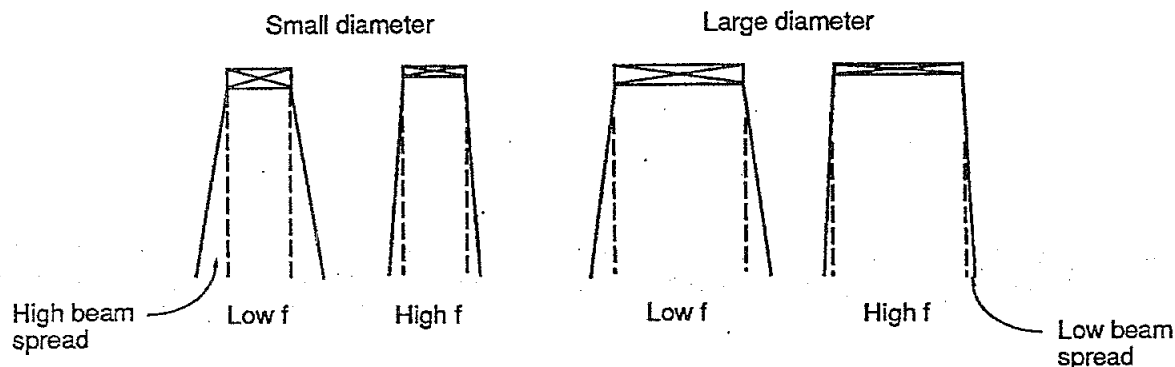


Figure 28. Beam spread related to transducer diameter and frequency.

Combined transducers

Combined transducers are those which have the transmitter and the receiver mounted in a single probe. This type of probe allows better resolution by focusing the beam and also permits optimization of properties of the transducer materials (Fig. 29).

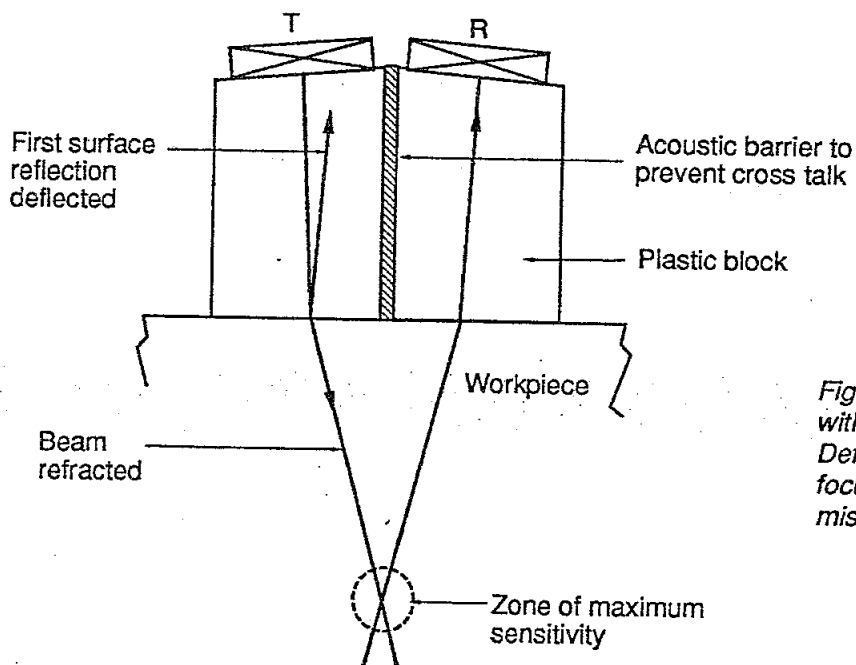


Figure 29. Focusing action with combined transducers. Defects above or below the focus zone could easily be missed.

APPLICATION TO WELD INSPECTION

At one time, ultrasonic examination of welds was not as widely used as radiography because radiography provided a permanent "picture" of the weld which could be filed and reviewed. With advanced UT systems, however, data can be downloaded to a computer and graphically reproduced anytime. With conventional manual ultrasonic examination the indication and the report from ultrasonic examination are much more dependent on the operator's skill. Nonetheless, there are many applications where radiography is just not economical or even possible. The sidebar gives advantages and limitations of ultrasonic examination for welds.

Advantages of Ultrasonic Tests

The desirable features of ultrasonic tests include:

- High sensitivity, permitting detection of minute defects.
- Great penetrating power, allowing examination of extremely thick sections.
- Accuracy in the measurement of flaw position and estimation of flaw size.
- Fast response, permitting rapid and automated inspection.
- Need for access to only one surface of the specimen.
- Does not pose radiation hazards as with radiography.

Limitations of Ultrasonic Tests

Test conditions which may limit the application of ultrasonic methods usually relate to one of the following factors:

- Unfavourable sample geometry. For example: size, contour, surface smoothness, complexity, and defect orientation.
- Undesirable internal structure. For example: grain size, structure porosity, inclusion content, or fine, dispersed precipitates.
- Skill, experience of the technician.

Equipment and material used in ultrasonic testing

For ultrasonic testing of welds you need:

- an appropriate flaw detector (to meet code requirements, usually requires calibrated gain control), sufficiently portable for the intended inspection operation, with spare batteries or AC converter
- cleaning and grinding equipment to access to the test surface
- an appropriate couplant material
- a selection of probes and cables
- calibration and reference blocks
- qualified operator
- procedure and acceptance standard.

Details of calibration and procedures are discussed later but in this section we will describe some general techniques for examining welds.

Although a liquid couplant is used to transmit the ultrasonic wave into the material, a smooth surface is still required. Grinding, although not always necessary, is often needed to remove spatter, weld reinforcement, or other roughness (Fig. 30). Excessive grinding that changes the contour of the surface should be avoided since the angle of entry of the beam could be affected.

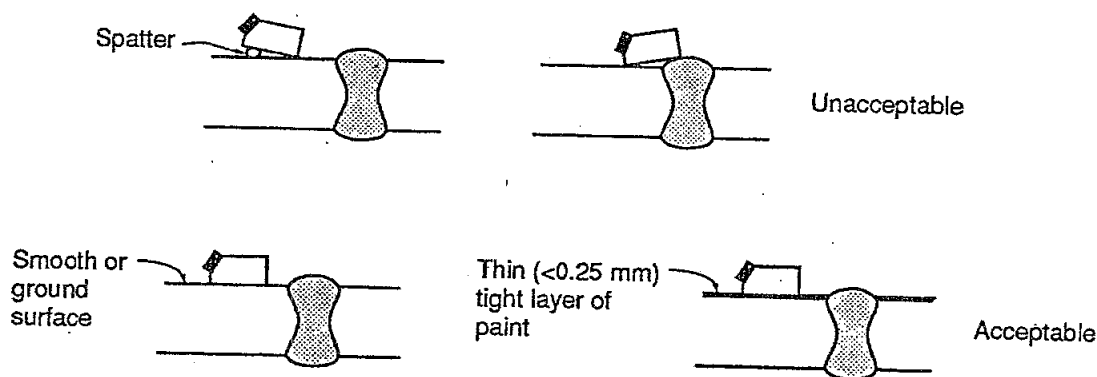
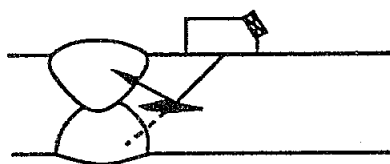


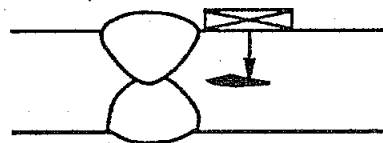
Figure 30. Surface condition required for ultrasonic examination.

Normal beam probes

Most ultrasonic examinations involve the use of both longitudinal waves (using normal probes) and transverse waves (angle probes). Normal probes are used initially to scan the parent material for laminations or other discontinuities that could interfere with a subsequent



A plate lamination can interfere with examination of the weld using an angle probe.



Scan for plate defects using a normal probe (longitudinal wave), preferably before welding.

Figure 31. Allowance for plate lamination near the weld.

examination of the weld (Fig. 31). The presence of defects in the plate may screen parts of the weld and inhibit inspection. Material adjacent to the weld should be inspected to ensure this does not happen. The reason for a normal beam inspection of the plate adjacent to the weld can be readily seen in Fig. 31. It is important to know that there are no laminar defects near the weld parallel to the inspection surface.

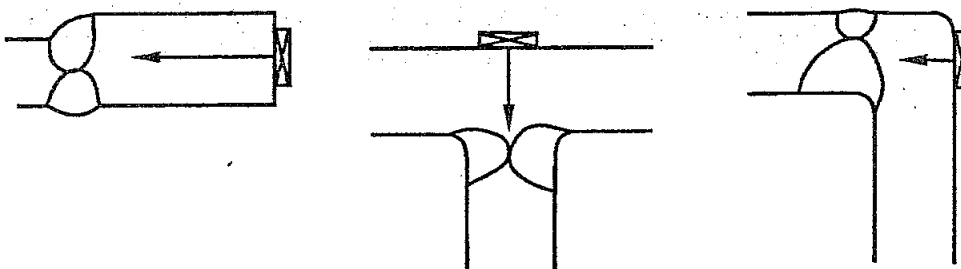


Figure 32. Normal probes for weld testing.

These probes are most sensitive to defects which lie at right angles to the direction of beam travel, e.g., laminations. Fig. 32 shows the use of normal probes for weld testing. While the signals from longitudinal beam inspection are relatively direct and easy to interpret, normal probes cannot be used to inspect the critical areas of a butt joint because of access due to the weld cap and the angle of preparation.

Some joints such as T and corner joints, however, do allow the use of normal probes as shown in Figs. 33 and 34. Scanning with a normal probe, however, is not usually used in isolation but rather should be considered in addition to angle probe testing (see Fig. 43 on page 29).

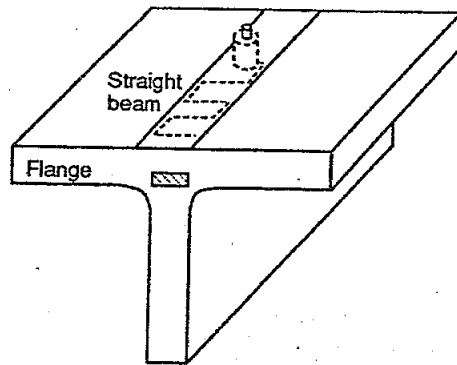
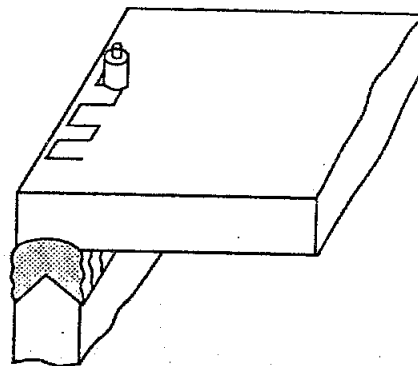


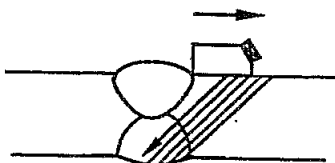
Figure 33. Technique for inspecting the fusion zone of T-joint

Figure 34. Technique for inspecting the fusion zone of double bevel corner welds.

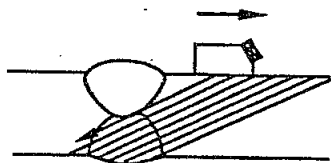


Angle beam probes

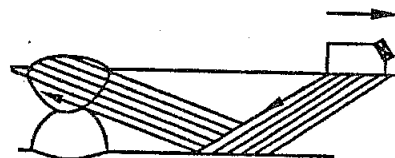
The geometry of the joint or access to a flat inspection surface usually dictates that an angle beam probe be used. These probes are typically normal transducers mounted on a plastic wedge at a wedge angle chosen to produce transverse waves in the specimen at an angle specified as part of the inspection procedure. Figs. 35 to 45 illustrate the use of angle probes in weld inspection.



Small angle, beam hits reinforcement.



Larger angle, beam hits weld.



Reflecting beam off the back wall allows inspection of the upper part of the weld.

Figure 35. Choice of probe angle to provide full examination of the weld.

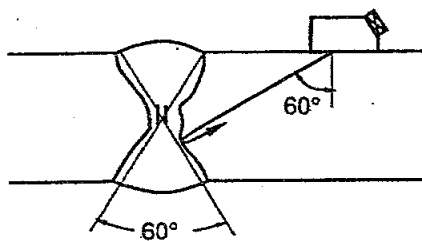


Figure 36. Probe angle chosen to match groove angle to give optimum reflection.

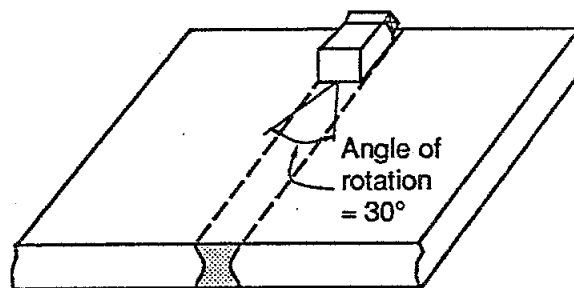


Figure 37. Supplementary technique for inspecting butt joints for suspected cross-cracking when the weld bead is ground flush.

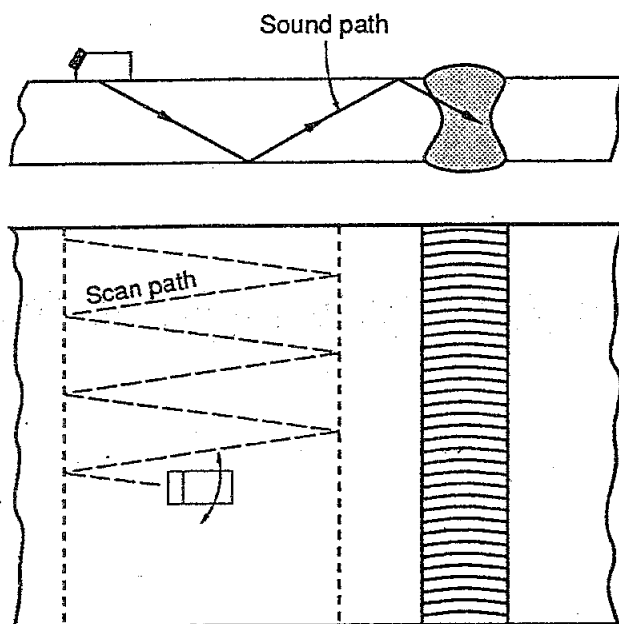


Figure 38. Inspecting butt joints with angle beams.

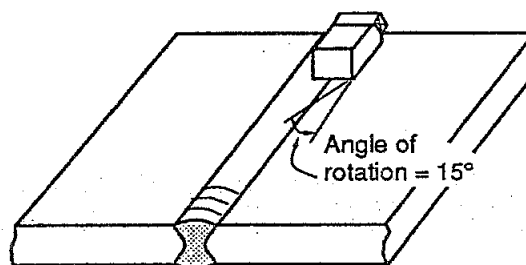
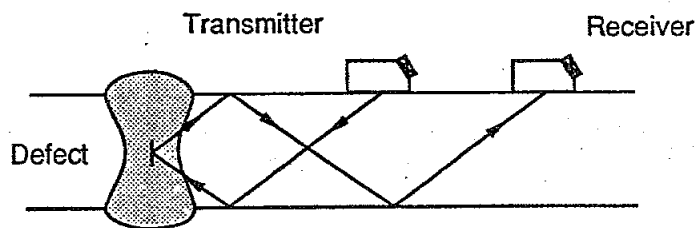


Figure 39. Supplementary technique for inspecting butt joints for suspected transverse cracking when the weld bead is not ground flush.

Figure 40. Two search-unit technique for use with thick weldments.



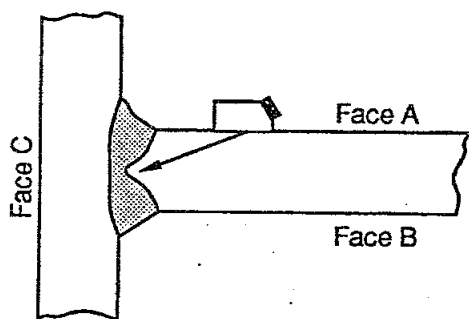


Figure 41. Technique for searching T-joints for discontinuities.

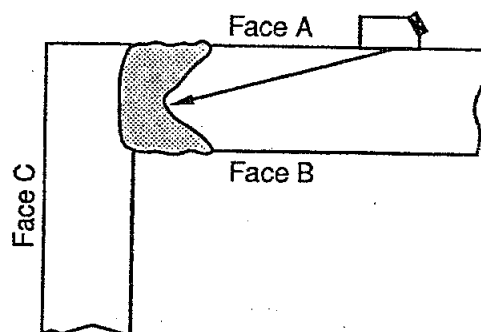


Figure 42. Technique for inspecting the weld volume of double bevel corner welds.

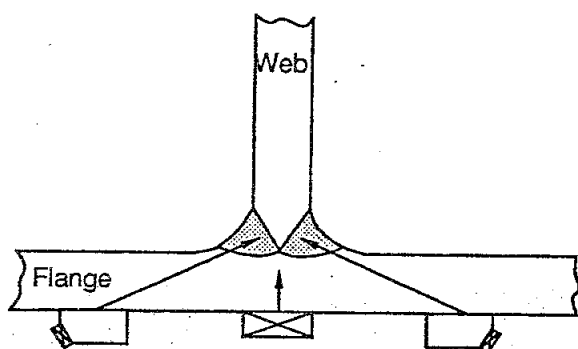


Figure 43. Alternate technique for searching T-joints for discontinuities using both normal and angle probes.

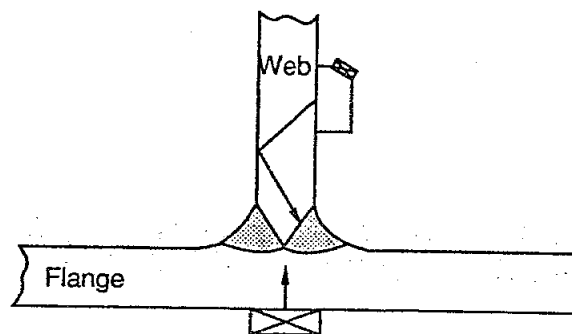


Figure 44. Alternative technique for searching T-joints for discontinuities.

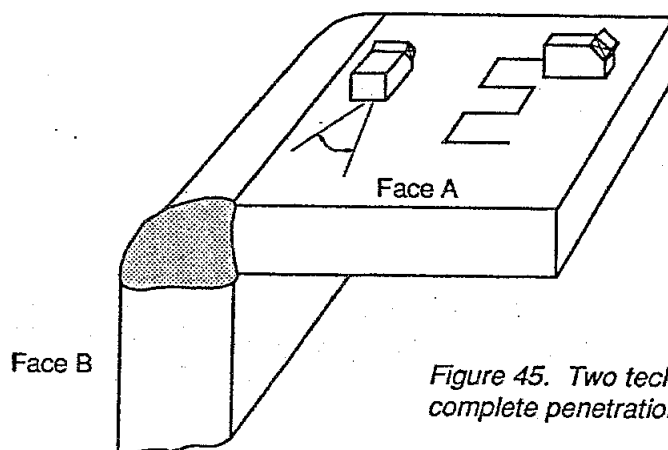


Figure 45. Two techniques for inspecting complete penetration corner welds.

Problems with backing bars

Not all reflections are caused by weld defects. Reflections can occur from plate edges, corners, gaps, and other surfaces making it difficult to distinguish which indications are caused by weld defects. In particular, difficulties in interpretation are encountered when welds have backing bars. Reflections may occur from various parts of the weld root and backing bar and multiple, internal reflections can make it difficult to locate the source (Fig. 46). Internal reflection can also change the mode of a transverse wave to a longitudinal wave (mode conversion). Since a longitudinal wave has a higher velocity, the apparent location of the reflector, as measured on the screen, changes.

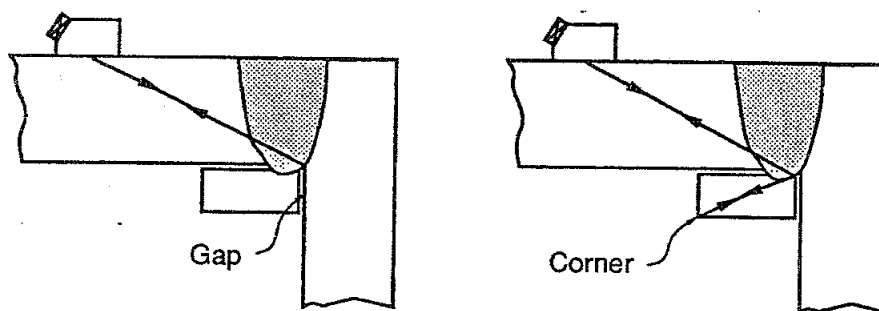


Figure 46. Backing bars may cause spurious reflections from gaps or corners.

Difficult materials

Difficulties in interpretation can be minimized by careful visual examination of the backing bar before welding, accurate calibration of UT equipment and probes, and careful attention to calculating location of reflectors.

The transmission of ultrasonic waves is affected by the structure of the material, particularly grain size. Some materials are difficult or impractical to inspect using ultrasonics because of the structure. Electroslag welds, for example, have a very large grain size and are difficult to inspect. Low frequencies (~ 1.0 MHz) are preferred for this application.

Similarly welds in austenitic stainless steels do not lend themselves to conventional ultrasonic inspection and extensive research has been undertaken to develop special procedures for this material. Fortunately, structural steels (e.g., carbon and low alloy steels) undergo a phase transformation when they cool producing a fine grain making them among the easiest materials for ultrasonic inspection.

Twin probe methods

While it is common to use single transducers for both transmitting and receiving signals, weld inspection can also be carried out using twin transducers, either to take advantage of the special characteristics of specific transducer materials or to meet the geometry or automation requirements of the inspection task. Figs. 47 to 49 illustrate the use of twin probes.

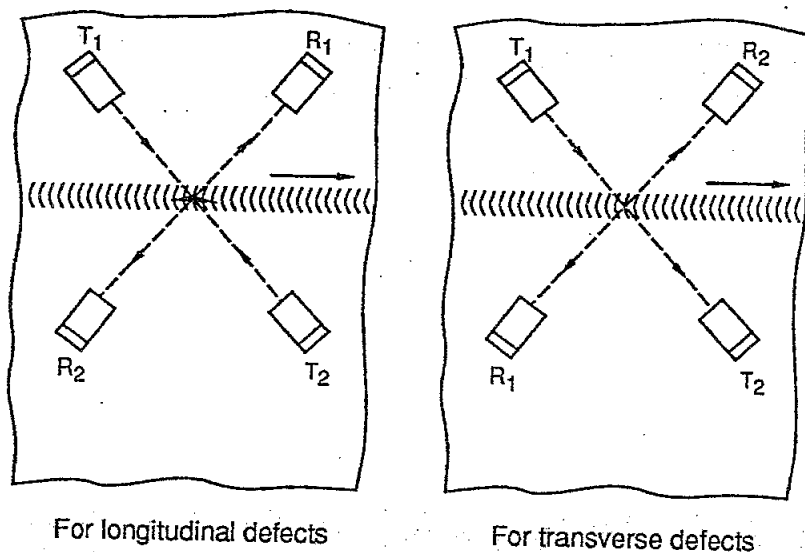


Figure 47. Testing of submerged arc welded joints by means of separate transmitting and receiving probes. T = Transmitter, R = receiver.

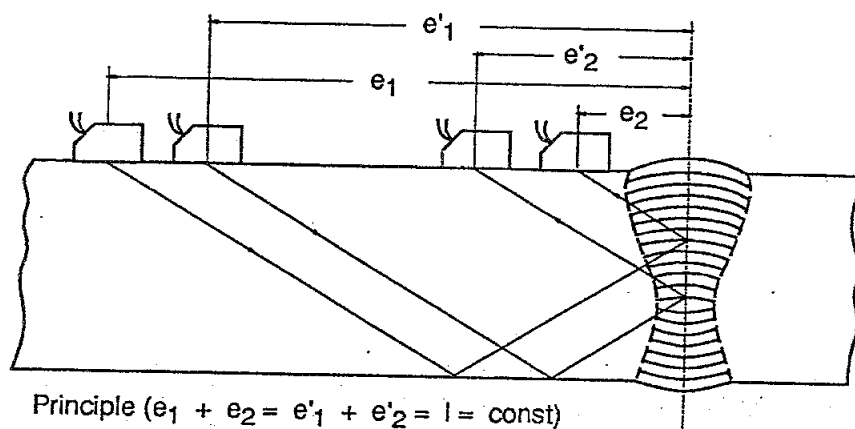
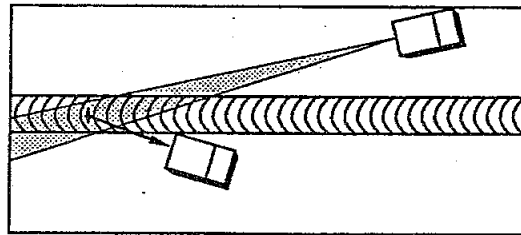
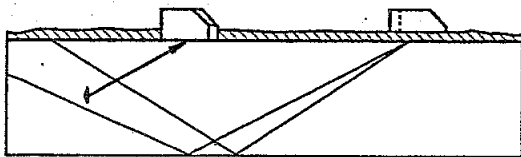


Figure 48. Pitch and catch method.



Plan view



Side view

Figure 49. Examination of transverse defects in a thick weld using tandem technique with the probes straddling the weld bead.

Through transmission

The through transmission technique with twin probes allows the transmitting probe to move relative to the receiving probe, and allows more flexibility in the test design. Fig. 50 illustrates an application. It is difficult to control two probes manually, and a jig is beneficial.

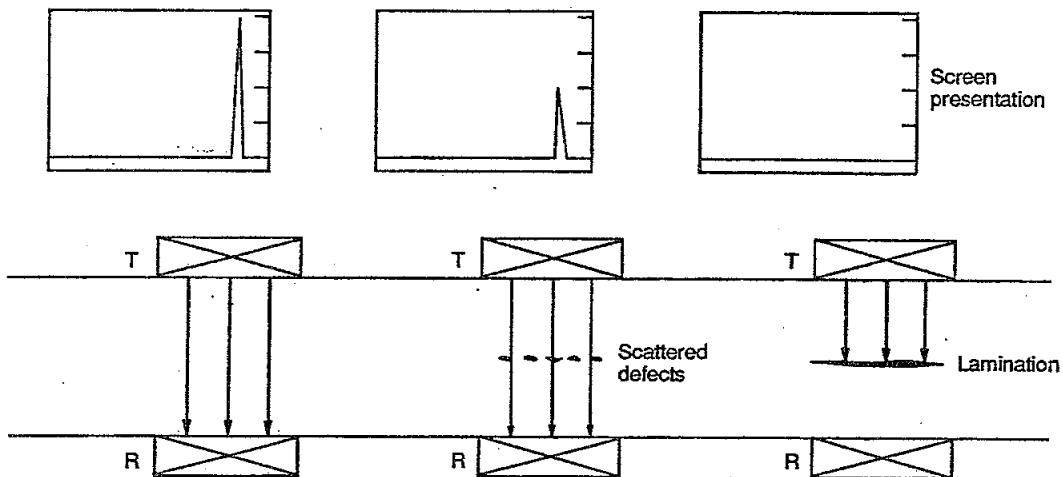


Figure 50. Through transmission testing.

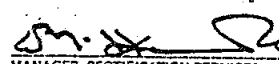
PROCEDURES AND CODE REQUIREMENTS

The inspector, if not a specialist in ultrasonic testing, must nevertheless be aware that there are certain key points to be checked when monitoring an inspection:

- Qualifications of the operator.
- There must be proof and records of regular calibration of equipment, flaw detectors, and probes.
- Availability and utilization of calibration and reference blocks.
- There must be a written inspection procedure available which is followed.
- Adherence to the procedure, especially the four steps of detecting, locating, identifying, and measuring discontinuity indications.
- Reporting.

Ultrasonic examination requires considerable skill on the part of the operator and should be carried out by qualified personnel. The qualifications of the operator should be checked by the inspector. CSA W59-1989 requires certification to the Canadian General Standards Board

Operator qualification

 Canadian Welding Bureau		CSA STANDARD W178 Qualification Code for Welding Inspection Organizations	
TEST EQUIPMENT OPERATOR CERTIFICATE			
Bobby Shaftoe			
has met the qualification requirements of CSA Standard W178 for a Test Equipment Operator as indicated by the CWB stamp			
Nondestructive Testing to CGSB Standards 48GP	4M 7M 8M 9M	 Mechanical Testing:	 Metallographic Testing:
while employed by: Inspection & Testing Lt (Ontario)			
a certified welding inspection organization whose designated personnel and standard test procedures for specific product categories have been approved by the Canadian Welding Bureau CSA Standard W178.			
T104 CERTIFICATE NO.	25 Nov. 1991 EXPIRY DATE	 MANAGER, CERTIFICATION SERVICES	
CONDITIONS: This card is the property of the Canadian Welding Bureau and can be recalled at any time. Fraudulent use may involve permanent cancellation.			
CWB FORM 4			

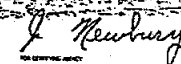
 Energy, Mines and Resources Canada		Énergie, Mines et Ressources Canada	
INDUSTRIAL ULTRASONICS - ULTRASONS INDUSTRIELS			
This certifies that Bobby Shaftoe			
has qualified according to the C.G.S.B. Standard 48-GP-7M, as:			
LEVEL NIVEAU	1	8/73	
LEVEL NIVEAU	2	10/79	
LEVEL NIVEAU	3	---	
SEE REVERSE FOR PERIOD OF VALIDITY LE VERSOUS MONTRER LA PÉRIODE DE VALIDITÉ		REG. NO. N° MATRICULE	209 

Figure 51. Examples of certificates for ultrasonic operators.

Equipment calibration

(CGSB) Standard 48-GP-7M "Certification of Nondestructive Testing Personnel (Industrial Ultrasonic Method)." Personnel are certified directly to CGSB and can be recognized as such as a Test Equipment Operator under the requirements of CSA W178 "Certification of Welding Inspection Organizations." Examples of wallet size certificates are shown in Fig. 51.

The relative intensity of ultrasonic reflections is measured using the gain control (or attenuator) to find the dB change. This control must be calibrated and certified accurate by the instrument manufacturer. The calibration should be checked at regular intervals (CSA W59-1989 specifies every 2 months) using a procedure approved by the manufacturer.

The rate at which the CRT trace moves across the screen can be adjusted but when set it should be steady. This is termed *horizontal linearity* and poor linearity means the distance measured on the screen is not proportional to distance in the piece being examined. The horizontal linearity should be within 5% according to CSA W59-89 and can be measured using procedures described in ASTM Standard E317.

Angle probe

The accurate location of the exit (or index) point on an angle probe is important since it is from this point that measurements are taken to determine the position of discontinuities. Determining the exit point is the first of several calibrations that can be done with the International Institute of Welding (IIW) ultrasonic block (Fig. 52). The procedure for

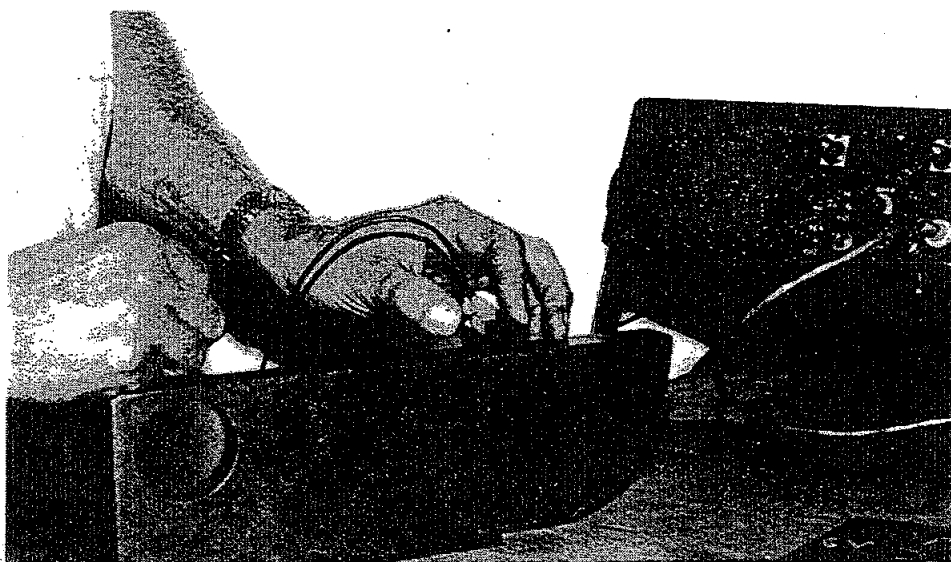


Figure 52. The IIW ultrasonic block being used for calibration.

locating (or checking) the exit point is to place the probe on the block in the position shown in Fig. 53. The probe is moved back and forth until the amplitude of the reflection is at a maximum. The exit point is then the point on the probe corresponding to the index marked on the block and it should be clearly marked on the probe.

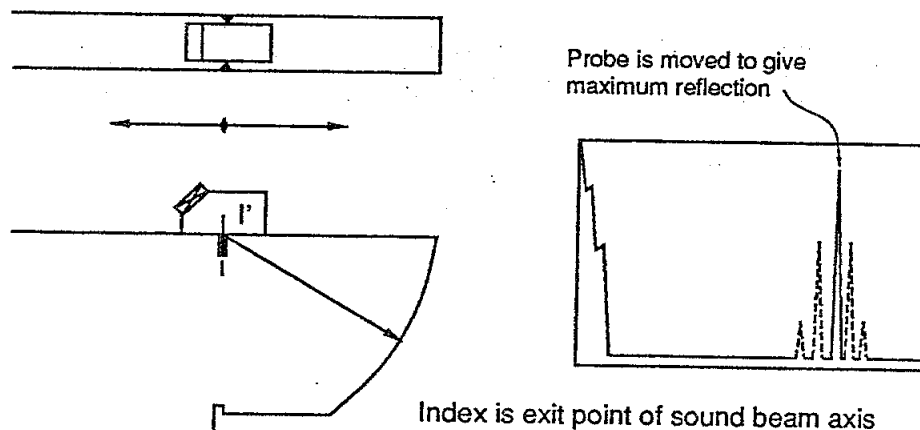


Figure 53. Determination of index point on angle beam probe.

In a similar way the angle of refraction of a probe may be determined on the IIW block. A round hole reflector is used since it reflects normal to its surface regardless of the angle when the beam is directed at the centre of the hole. The probe is placed as shown in Fig. 54 and moved back and forth to find the maximum amplitude of the reflection. The angle is the value on the scale corresponding to the exit point on the probe. The angle must only be checked after the exit point has been determined.

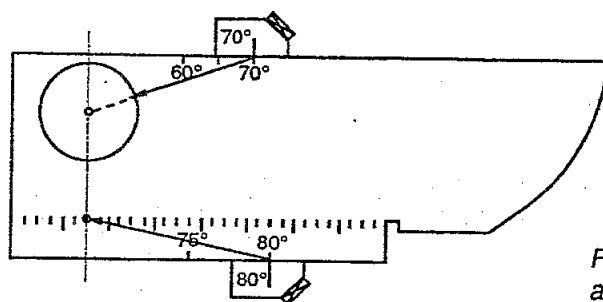


Figure 54. Determination of the angle of refraction.

Distance calibration

The horizontal deflection of the trace on the CRT screen represents beam path distance and must be calibrated to represent a known distance. For a normal probe (longitudinal mode) the probe can be placed on the side of the IIW block (Fig. 55) and the instrument adjusted to obtain indications at 25, 50, 150 mm, etc., on the screen. This would be 1, 2, 3 in., etc., on the SI block. For the transverse mode, the angle probe is placed as in Fig. 56 and the sweep adjusted to give indications at 100 and 200 mm. Similar procedures are used with other types of calibration blocks.

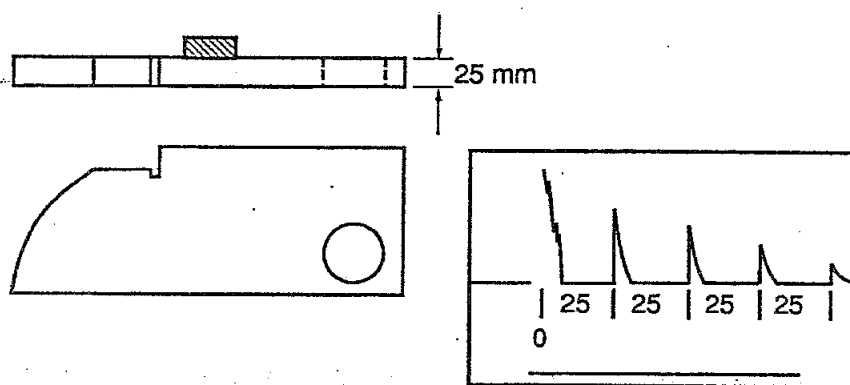


Figure 55. Distance calibration for a normal probe.

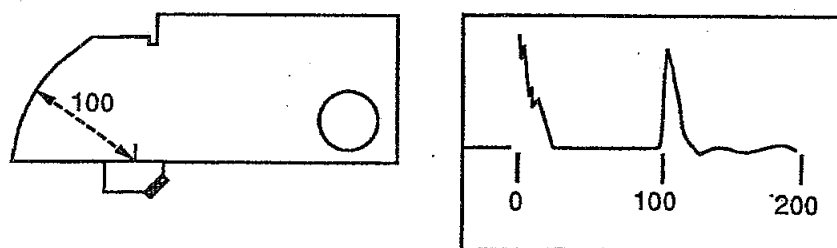


Figure 56. Distance calibration for an angle probe.

Sensitivity calibration

Vertical deflection represents the amplitude of a reflection and the sensitivity is adjusted such that a reference reflector causes a given height on the screen. Note that the reference reflector is arbitrary and does not necessarily represent any particular weld defect. Various types of reflectors may be specified for amplitude calibration such as flat bottom holes, side holes, or slots.

For the longitudinal mode the back wall reflection is used for amplitude calibration. For the shear (transverse) wave mode CSA W59-M1989 requires a 1.5 mm hole to be used when calibrating with the IIW block (Fig. 57). Other calibration methods and reference reflectors may be specified.

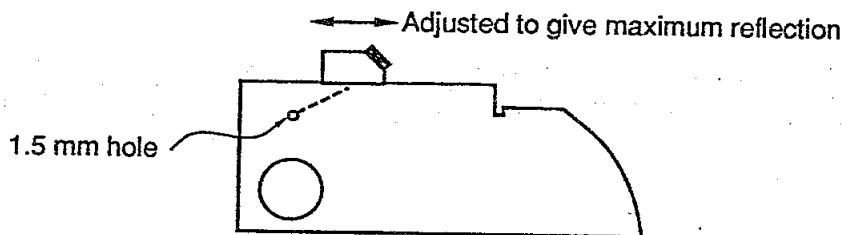


Figure 57. Sensitivity calibration from a 1.5 mm side hole using the IIW block.

Resolution

Resolution is checked by using a reference block with closely spaced reflectors. The resolution reference block shown in Fig. 58 has three closely spaced holes for each of three probe angles. The screen indications should show three distinct peaks.

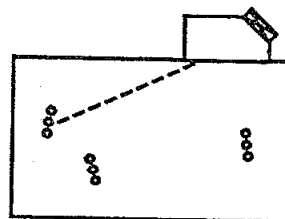


Figure 58. Method for checking resolution.

DAC curve

Because of attenuation of the ultrasonic wave in the material, the amplitude of the reflected wave depends on the sound path distance. A correction for this effect can be made by constructing a 'distance-amplitude correction' (DAC) curve. One method of doing this is to place the probe on a calibration block in successive positions such that the beam bounces off the back wall and must travel longer distances to the reflector. Fig. 59 illustrates the method of establishing a DAC curve according to ASME requirements.

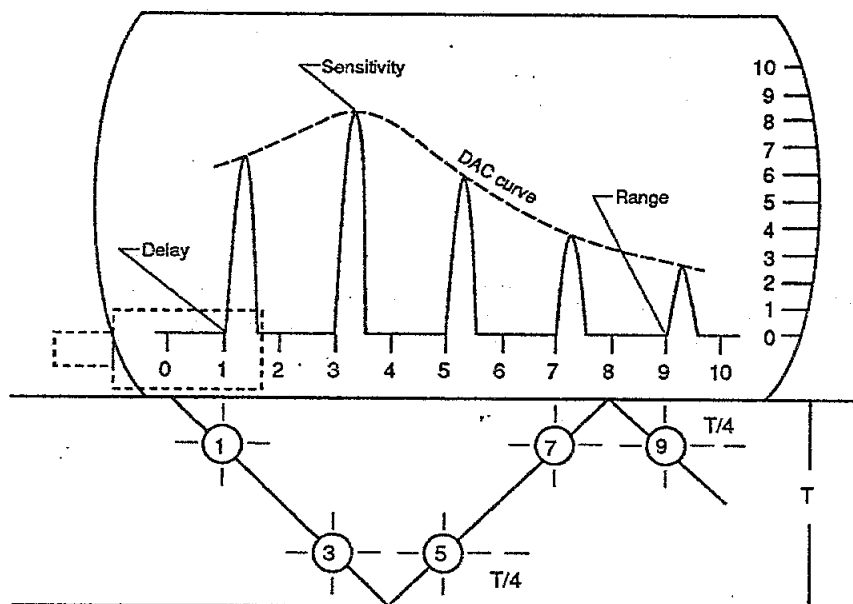


Figure 59. Typical 'distance amplitude correction' curve (angle beam method). From ASTM E164.

It should be noted that some standards (e.g., CSA W59-89 and AWS D1.1) do not require a DAC curve to be constructed. Instead, a fixed attenuation factor is assumed to apply. Some ultrasonic instruments have electronic DAC which can be calibrated then stored by the instrument to electronically correct the amplitude of a reflection displayed on the screen.

Reference blocks

It is common practice to develop a specific reference block for any inspection task which is large enough, repetitive enough, or complex enough to make it worthwhile. For field inspection of pipe welds, for example, one might prepare a reference block of the same material, containing the same weld geometry, and having the same radius and thickness of the pipe to be inspected. The reference block could be of a convenient size, so that it is carried around by the inspector. It would also contain artificial defects, perhaps drilled holes of a specific size and angle related to the inspection task.

Inspection procedures

Most weld inspection procedures involve four steps which may be considered to represent increasing difficulty.

1. Detecting discontinuities
2. Locating discontinuities
3. Identifying discontinuities
4. Measuring discontinuities.

For the initial search, it is necessary to have the sensitivity level sufficiently high that no significant reflectors will be missed. The scanning procedure will typically call for a minimum scanning level which could be established by obtaining an echo on the screen from a standard reflector (drilled hole) on the reference block, then adding a specified number of decibels (dBs) of amplification.

The operator then scans the weld area in a pattern which ensures that the ultrasonic beam passes through the areas of interest for the full inspection length of the weld. Typical inspection patterns are shown in Figs. 60 and 61.

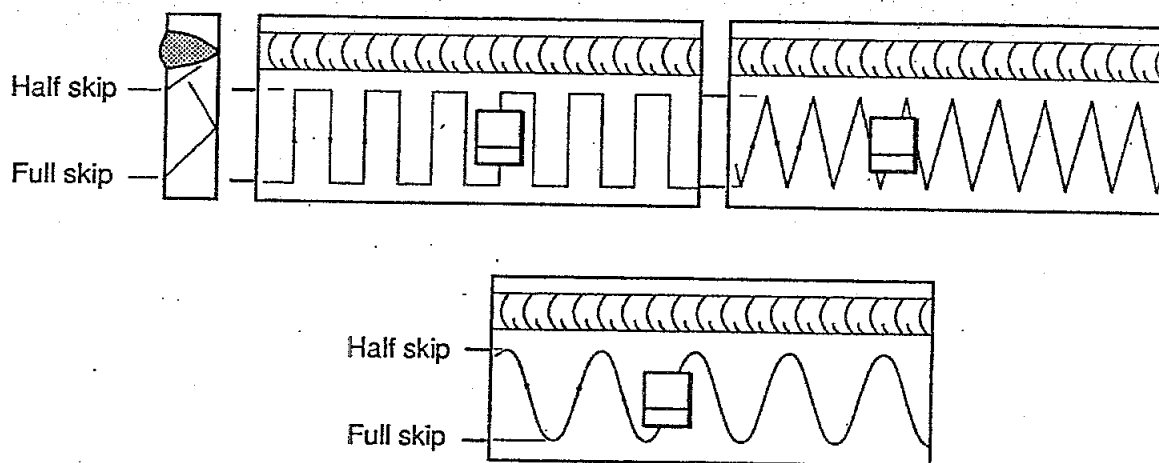


Figure 60. Probe scanning patterns showing displacement of probe.

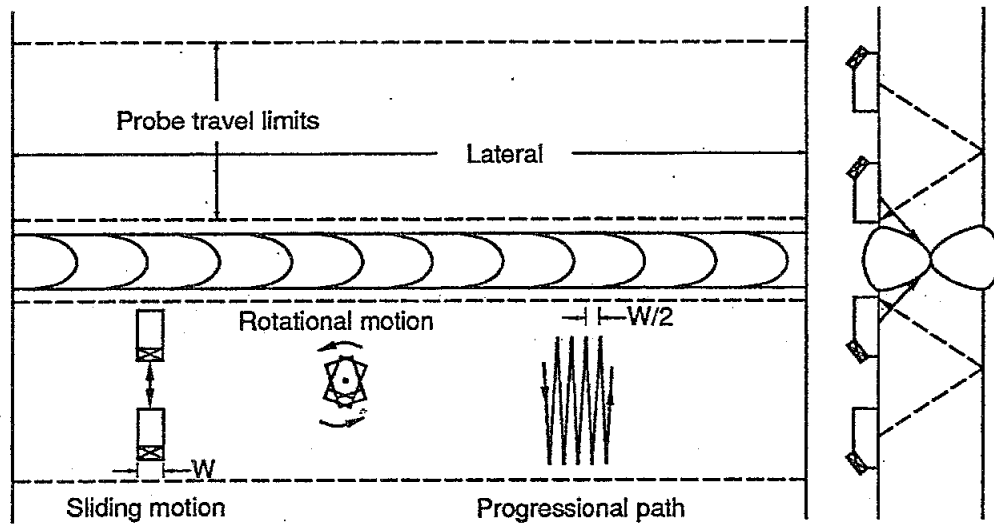


Figure 61. Scanning method for longitudinal defects, with probe travel limits.

Locating discontinuities

Any indications which are noted during the scanning stage and which exceed an established percentage of the reference level are subjected to further evaluation. The first step is to determine their exact position within the weld. See Figs. 62 and 63.

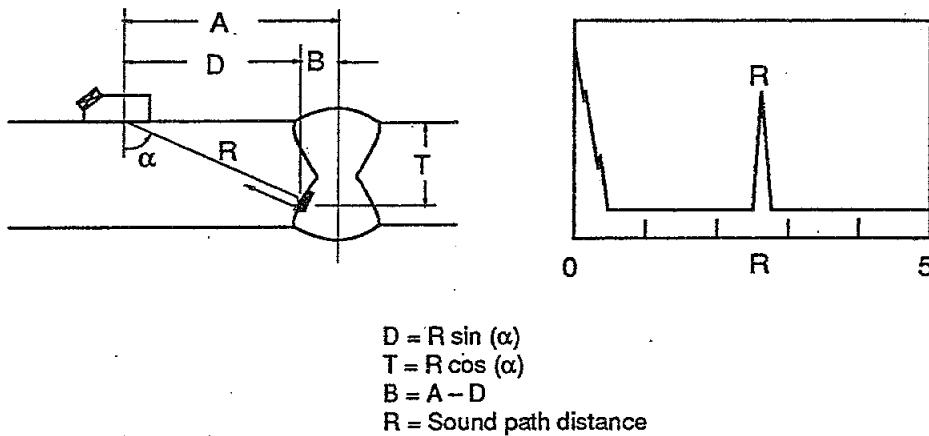


Figure 62. Equations to locate defect using the angle probe.

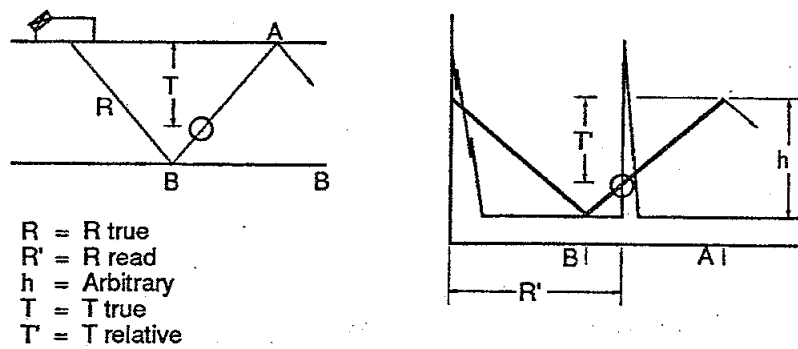


Figure 63. Sound path sketched on screen.

Several commercial aids are available to help picture the beam path in relation to the signal and the inside geometry. Computer programs on the most modern instruments have this type of information internalized. Fig. 64 illustrates a typical aid for locating flaws.

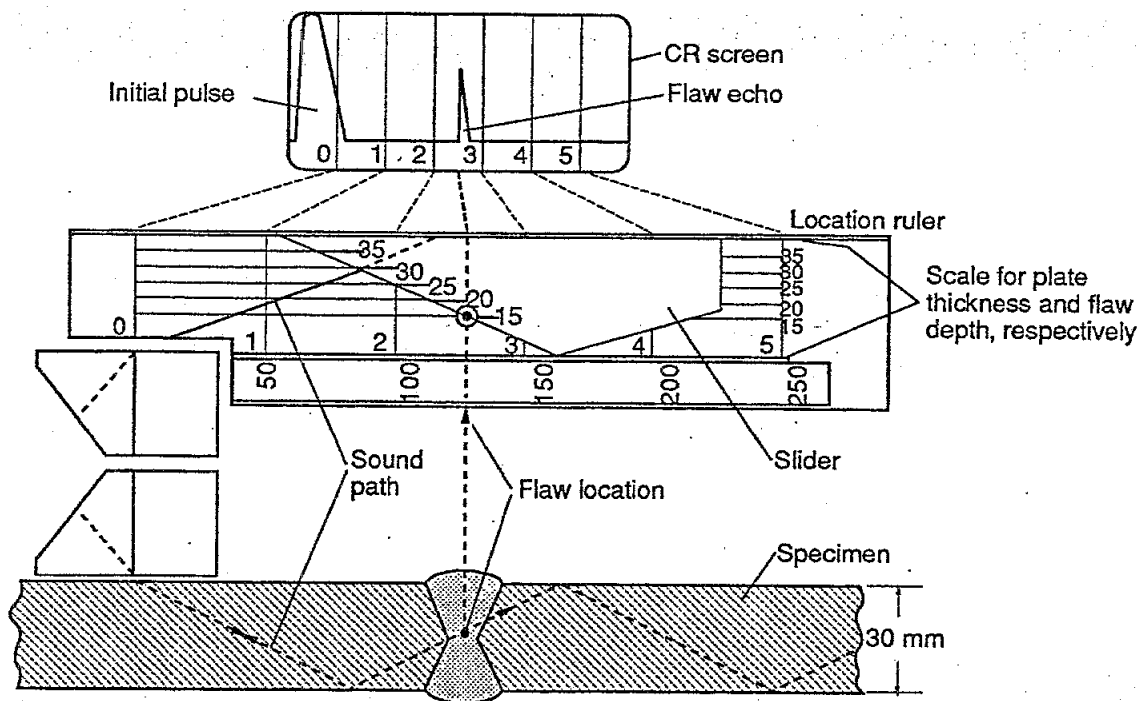


Figure 64. Locating flaws with the Krautkrämer locating rule for testing welded joints.

Identifying discontinuities

The next step in the process is to attempt to identify the discontinuity. This requires a knowledge of the type of signal which is typical of various shapes and types of defects, the geometry of the weld, and the welding process.

The procedure for characterizing discontinuities usually involves noting the reflection when observed from different directions. Selective movement of the probe (Fig. 65) causes the beam to approach the discontinuity from different directions and the amplitude of the reflection will depend on the shape of the discontinuity. Discontinuities can be classes as:

- Spherical (single pores, widely spaced porosity)
- Cylindrical (hollow beads, slag lines)
- Planar (lack-of-fusion, cracks)

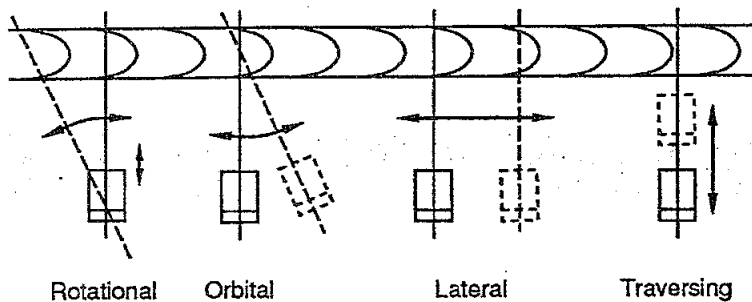


Figure 65. Probe motions for angle beam scanning to characterize discontinuities.

Spherical reflectors give the same amplitude reflection from any direction although the amplitude may be rather small (Fig. 66). Cylindrical reflectors only show constant amplitude for directions normal to the axis of the cylinder (Fig. 67). Planar structures, however, show a drop of amplitude when the beam is not normal to the plane of the discontinuity (Figs. 68 and 69).

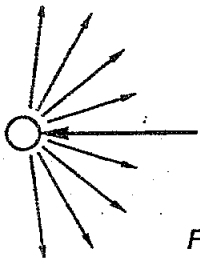


Figure 66. Spherical pore: scatter in three dimensions.

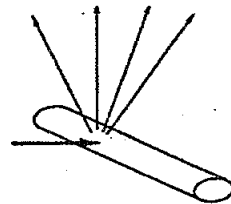


Figure 67. Cylindrical cavity: scatter in two dimensions.

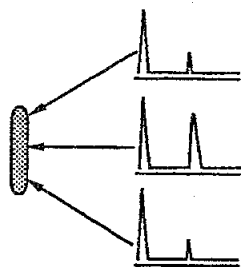


Figure 68. Planar reflector showing drop in amplitude when the beam is not normal to the reflector.

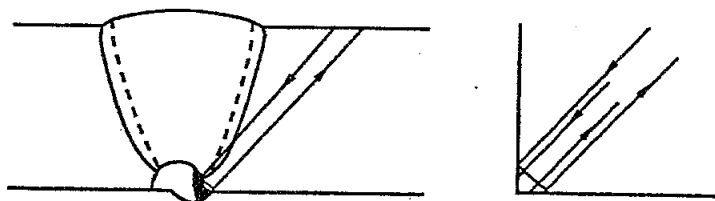


Figure 69. Lack of penetration at root of a single groove weld acts like a corner reflector.

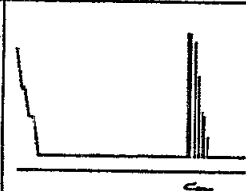
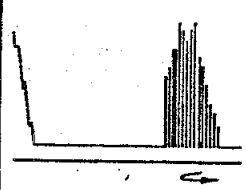
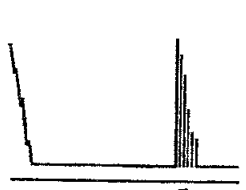
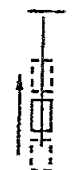
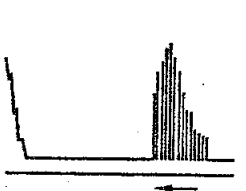
Probe Motion	Successive Echo Signals	Remarks
 Rotation		For ragged tearlike defect, pattern is as shown. Ragged edge of pattern indicates diffraction of beam and consequent loss of echo height.
 Orbiting		Pattern ragged in form, roughly triangular, with depression at top.
 Lateral		With lateral probe movement the amount of echo travel is dependent entirely upon lie of defect. Any increase in travel indicates change in probe/defect distance. Successive echoes increase rapidly to a maximum as beam crosses defect. Pattern width and probe travel with full echo are a function of defect size.
 Traversing		As the probe is advanced toward the defect the edge of the beam makes contact and the echo height increases rapidly at first. Die-away is rapid. Pattern width is a function of vertical span of defect but is also dependent upon probe angle.

Figure 70. Typical echo patterns from ragged defect such as a crack.

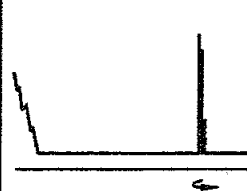
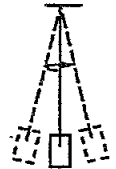
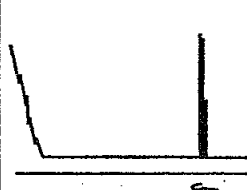
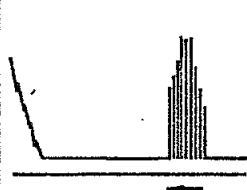
Probe Motion	Successive Echo Signals	Remarks
 Rotation		Pattern very narrow. Die-away rapid.
 Orbiting		Pattern very narrow. Die-away rapid.
 Lateral		Constant echo height. No die-away. Trace does not move.
 Traversing		As the probe is advanced toward the defect and the edge of the beam makes contact, the echo height increases very rapidly. The maximum is held for a very short time. Die-away is rapid.

Figure 71. Typical echo patterns from specular reflector such as lack of penetration or lack of fusion.

It may be possible to distinguish a planar reflector with a ragged surface, such as a crack, from one with a smoother, more reflective (specular) surface. Figs. 70 and 71 illustrate details of echo patterns from these two types of planar discontinuities.

It is difficult to accurately measure the true length of discontinuities because the reflected amplitude depends on so many factors. But most codes require a characteristic length to be measured using a prescribed method. The most common method is to identify the position on the

Measuring
discontinuities

surface which corresponds to 50% of the maximum amplitude (i.e., 6 dB drop). This is based on the idea that when the beam axis reaches the edge of the discontinuity, only half the beam is reflected. Fig. 72 illustrates this method.

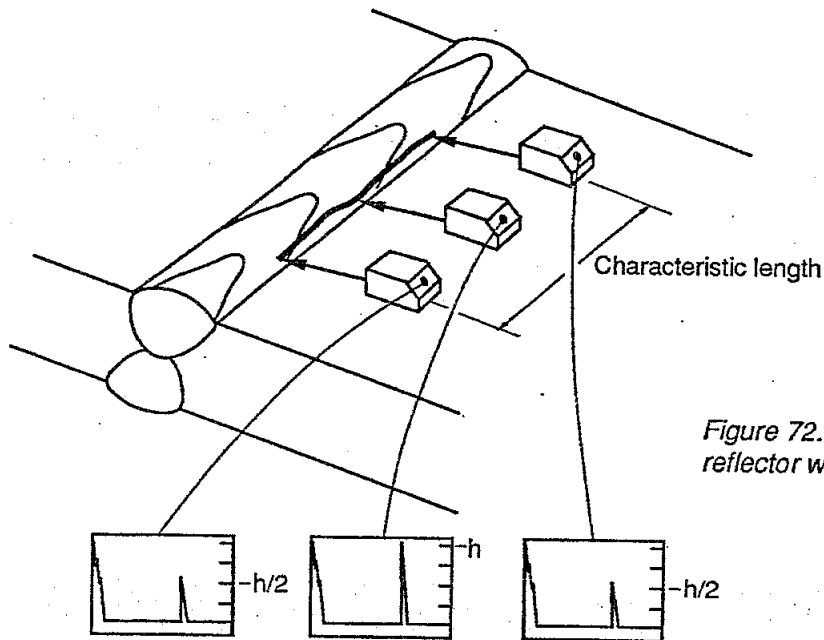


Figure 72. Measurement of length of long reflector with angle beam probe.

Other methods are also used for determining a characteristic size. For example, the maximum amplitude method is based on the fact that for some orientations the maximum amplitude occurs from the end of the reflector. The distance between two peaks is measured and the discontinuity height determined from geometry. Fig. 73 illustrates this approach.

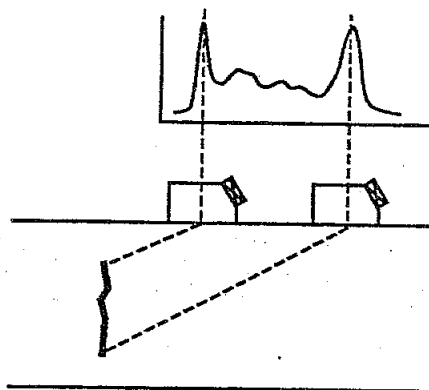


Figure 73. Determining defect height using the maximum amplitude method.

Evaluation of Indications

There are two general approaches for the evaluation of flaw indications: one based on general quality of workmanship (quality control criterion) and the other based on a more precise evaluation of the fitness-for-purpose criterion). The latter approach is being used increasingly in

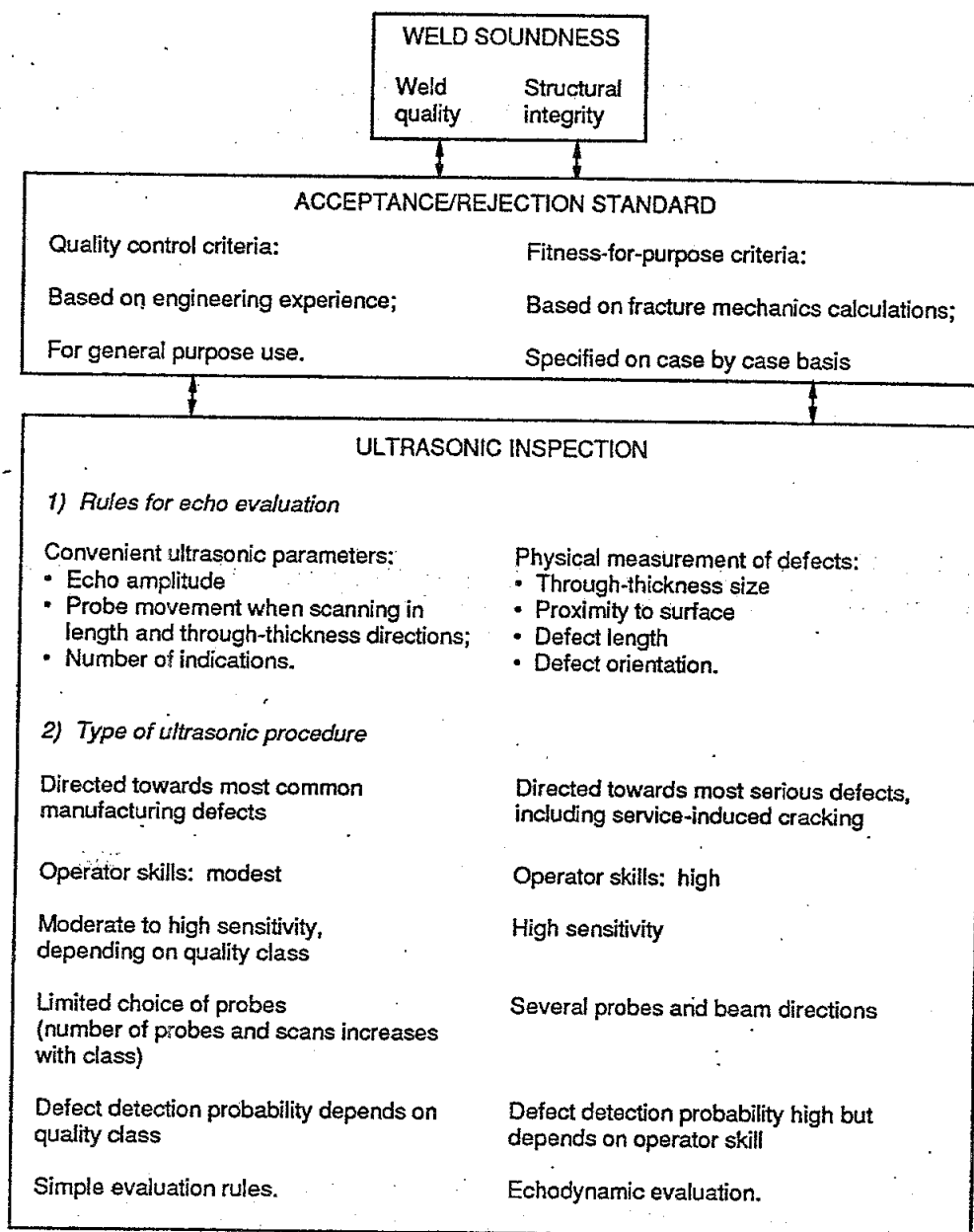


Figure 74. The relation between the freedom from defects of the weld, the defect acceptance standard and aspects of the ultrasonic procedure as they apply to the quality control and fitness-for-purpose functions of ultrasonic examination.

the evaluation of flaws found in service and in cases where a repair would be costly or risky. The method requires detailed knowledge of the stress the weld is subject to, the environment, material properties, and an accurate knowledge of the flaw size and location.

For most ultrasonic inspections performed during the course of fabrication the quality control approach is used. Arbitrary standards are set for the acceptance or rejection of indications and no attempt is made to establish whether any particular flaw is likely to affect the integrity of the structure. A comparison of the two approaches is shown in Fig. 74. In this module we will discuss briefly some of the acceptance criteria used in codes based on this quality control approach.

CSA W59-M1989

The method used in CSA W59-M1989 and other similar structural welding codes has a number of simplifying features. Acceptance or rejection of indications is based on amplitude and length. No attempt is made to identify the flaw, for example whether it is a crack or porosity, and therefore the seriousness of the flaw is not addressed. The procedure involves the following steps:

- Calibrate sensitivity using the 1.5 mm side drilled hole in the IIW block, adjusting the height to between 50% and 75% full screen height to provide the reference level. Note the gain setting (in dB). This is the reference level 'b'.
- A DAC curve is not required, but an attenuation factor of 1 dB per 12.7 mm of sound path greater than 25.4 mm is assumed. Thus, measure the total sound path, subtract 25.4 mm, and divide the remainder by 12.7. This gives the attenuation factor 'c'.
- Adjust the gain control to bring the peak of the indication to the reference level (horizontal line) on the screen. Note the gain control reading. This is the indication level 'a'.
- The indication rating 'd' is then:

$$d = a - b - c$$

(*a* and *b* may have opposite signs depending on whether the sensitivity control is marked as gain or attenuation).

- Measure the indication length using the 6 dB drop method.

- Accept or reject indications according to tables provided for statically loaded or dynamically loaded structures. The table for statically loaded structures is shown in Table 3. Note that as 'd' becomes larger it represents a smaller reflector.

Table 3. Ultrasonic acceptance criteria for statically loaded structures (CSA W59-M1989).

Reflector Severity	Minimum Acceptance Levels (Decibels)													
	Weld Thickness (mm) and Transducer Angle													
	8 to 20	>20 to 38	>38 to 63			>63 to 100			>100 to 150			>150 to 200		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Large reflectors	+8	+3	-1	+2	+4	-4	-1	+1	-7	-4	-2	-9	-6	-4
Small reflectors	+9	+4	+1	+4	+6	-2	+1	+3	-5	-2	0	-7	-4	-2
Minor reflectors	+10	+5	+3	+6	+8	0	+3	+5	-3	0	+2	-5	-2	0

Large Reflectors: Any discontinuity, regardless of length, having a more serious rating (smaller number) than this level shall be rejected.

Small Reflectors: Any discontinuity longer than 20 mm having a more serious rating (smaller number) than this level shall be rejected.

Minor Reflectors: Only those discontinuities exceeding 50 mm in length and having a more serious rating (smaller number) than this level shall be rejected.

Refer to original for notes.

As an example you are inspecting a weld in 25 mm thick plate with a 70° probe. The reference level set is 42 dB. An indication is detected and when the gain is adjusted to bring the indication height to the reference level it reads 46 dB. The sound path measured from the screen is 38 mm and the indication length using the 6 dB drop method is 30 mm.

Indication level 'a' = 46 dB

Reference level 'b' = 42 dB

Attenuation factor 'c' = $\frac{38 - 25.4}{12.7} = 1 \text{ dB}$

'd' = 46 - 42 - 1 = 3 dB

According to Table 3 (statically loaded structure) this would be rejected as a small reflector because the length is greater than 20 mm.

ASME

The procedures in ASME also depend on amplitude relative to a reference level set by calibration to a side hole but there are some important differences. Steps involved are:

- Set reference level using appropriate side hole:

3/32 in.	for weld thicknesses	< 1 in.
1/8 in.	" " "	1 – 2 in.
3/16 in.	" " "	2 – 4 in.
- Determine the DAC (distance amplitude correction) curve.
- Investigate all indications giving a response greater than 20% of the DAC reference level. Evaluate the reflector as linear or spherical and attempt to identify it as a crack, lack of fusion, slag, etc.
- Determine the length and location.
- Accept or reject on the basis of amplitude, discontinuity type, and size. For example ASME Section VIII Division 1:
 - a) imperfections interpreted as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length;
 - b) all other linear type imperfections are unacceptable if the amplitude exceeds the reference level and the length exceeds:

1/4 in. for T up to 3/4 in.

1/3 T for T from 3/4 in. to 2 1/4 in.

3/4 in. for $T > 2 1/4$ in.

where T is the thickness of the weld being examined.

It is emphasized that these brief summaries are given here to illustrate the basic methods and the original documents must be consulted for the complete procedures and acceptance criterion.

Reporting

In most ultrasonic inspection the only record is the operator's report based on interpretations made at the time of inspection. It is important, therefore, that these reports are clear, accurate, and contain adequate information. Standards, such as ASTM E164, define parameters that should be reported (see sidebar) and fabrication codes such as CWS W59 and AWS D21.1 contain recommended formats for reporting results. Reports should indicate the code or specifications, acceptance

ASTM E164 – Report parameters

11. Report

- 11.1 Each weld examination should be recorded on a report form which includes at least the following information.
 - 11.1.1 Weld types and configurations tested, including thickness dimensions. Descriptive sketches are usually recommended.
 - 11.1.2 Automatic defect alarm or recording equipment or both, if used.
 - 11.1.3 Special search units, wedges, shoes, or saddles, if used.
 - 11.1.4 Rotating, revolving scanning mechanisms, if used.
 - 11.1.5 Stage of manufacture at which test was made.
 - 11.1.6 Surface or surfaces from which the test was performed.
 - 11.1.7 Surface finish.
 - 11.1.8 Couplant.
 - 11.1.9 Method used.
 - 11.1.10 Technique used.
 - 11.1.11 Description of the calibration method and method of correlating indications with defects.
 - 11.1.12 Scanning.
 - 11.1.13 Mode of transmission.
 - 11.1.14 Type and size of transducer.
 - 11.1.15 Test frequency.
 - 11.1.16 Instrument identification information.
 - 11.1.17 Defect description (depth, location, length, height, amplitude, and character.

criteria, and name and certification of the inspector. CSA W59-1989 Appendix F has a suggested format for the report. Fig. 75 illustrates part of another format that emphasizes the sketch of the weld and location of reflectors. In addition, the inspection organization should have up-to-date records of operator qualification and equipment calibration.

INSTRUMENT: _____ Date: _____

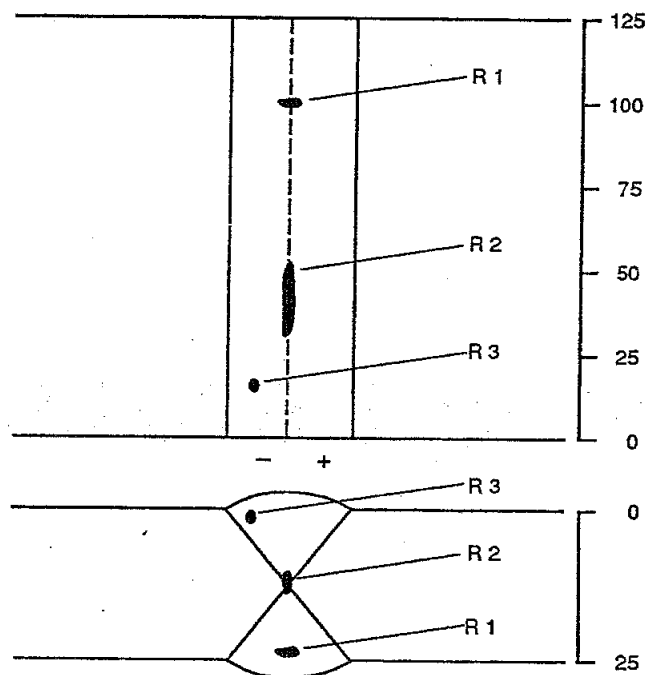
SENSITIVITY: 48 dB at 80 mm TRANSFER CORRECTION: 6 dB Loss

CALIBRATION: 100 mm radius = 100 mm

WELDMENT: Specimen Butt No. US 31 25 mm thick

Double Vee

PROBE: Frequency _____ Angle _____ Size _____ Model _____



Reflector	Range	Depth	Lateral	Longitudinal		Length	Net dB Gain	INTERPRETATION	Disposition
R 1	60	20	0	100	100	0	4	TRANSVERSE CRACK	REJ
R 2	70	12	0	30	50	20	-6	INCOMPLETE PENETRATION	REJ
R 3	110	5	-5	20	20	0	10	GAS HOLE	OK

Figure 75. Part of a typical UT report.

Summary

Ultrasonics as a nondestructive method of inspecting welds has been growing in use, and the extensive research being undertaken is resulting in sophisticated systems capable of providing three-dimensional images of defects in welds. The bulk of industrial UT of welds, however, still uses the conventional manual technique which is highly dependent on the skill of the operator. The UT examination of welds is conducted by qualified individuals but the inspector requires a good knowledge of the method in order to check qualifications, procedures, and discuss interpretations.

This module has presented the basis of ultrasonic testing, describing types of waves, wavelength, attenuation and refraction. The equipment used has been described together with the methods of displaying information on a screen. Various newer techniques have also been mentioned.

The application to inspecting welds has been covered, describing the types of probes used, their location, and scanning methods. Methods of calibrating UT equipment and probes has been described. Various procedures as required by codes and standards have been covered together with the means of evaluating results.

It is hoped this will provide the inspector with a sound understanding of the method and facilitate the inspector's task when ultrasonic examination is specified.

Additional Resource

Nondestructive Testing Handbook, Volume 7 (Ultrasonic Testing)
American Society for Nondestructive Testing, Columbus, Ohio.

GUIDES AND EXERCISES

MODULE 19

ULTRASONIC INSPECTION

ULTRASONIC INSPECTION

MODULE 19

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to learn something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the WIC closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending seminars which are given periodically, and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

After working through each guide, check your answers (starting on page 62) for accuracy. If any of your answers are wrong, re-study the guide subject matter in the text until you understand it before moving on to the next guide.

Guide 1

Read carefully pages 1 to 7 and answer the following questions:

1. Approximately what is the upper limit of human hearing?
 - a) 15 Hz
 - b) 15 kHz
 - c) 15 MHz
2. What is a typical frequency of ultrasonic testing of welds?
 - a) 2.25 MHz
 - b) 2.25 kHz
 - c) 2.25 Hz
3. If an ultrasonic wave in a block of steel has a wavelength of 1.3 mm and travels at a velocity of 5.85×10^3 m/s, calculate the frequency.
4. Do transverse waves in a solid travel faster or slower than longitudinal waves?
5. True or false?

"The energy carried by a wave is proportional to the square of the amplitude."
6. If the amplitude of a wave is reduced to 25% what is the corresponding drop in dB? (Hint: you can figure it out from the information on page 6 but you could also use logarithm tables or a calculator.)
7. The decrease in energy of an ultrasonic wave as it travels through a material is known as—
 - a) amplitude
 - b) amplification
 - c) attenuation

Guide 2

Read carefully pages 7 to 10 and answer the following questions:

1. Piezoelectric crystals can—
 - a) change mechanical pulses into electrical pulses
 - b) change electrical pulses into mechanical pulses
 - c) do both a) and b)
2. What determines the natural frequency of a given piezoelectric transducer?
 - a) The amplitude of the voltage applied.
 - b) The transducer thickness.
 - c) The frequency is set by the material being inspected and cannot be changed.
3. Name one piezoelectric material.
4. In conventional ultrasonics the wave is injected into the specimen as:
 - a) a continuous wave at the natural frequency of the transducer
 - b) a short pulse containing several oscillations at the natural frequency
5. Why is good acoustic contact between the transducer and the test specimen needed?
6. True or false?

"A couplant is only needed if the surface is rough."

Guide 3

Read carefully pages 11 to 18 and answer the following questions:

1. Draw a block diagram of the basic pulse-echo equipment from memory then compare your sketch with Fig. 10.
2. In A-scan display the vertical displacement of the trace represents:
 - a) the amplitude of the reflected wave
 - b) the size of the reflector
 - c) distance

3. In A-scan display the horizontal displacement of the trace is calibrated to represent:
 - a) the amplitude of the reflected wave
 - b) the size of the reflector
 - c) distance
4. In what units is the gain control (or attenuator) marked?
5. What type of display gives a cross-sectional view showing length and depth of discontinuities?
6. Give an example where the entire specimen is immersed in water which acts as the couplant.
7. True or false?

"Acoustic emission relies on detecting very small amounts of mechanical energy released from such things as growing cracks or structural discontinuities under load."

Guide 4

Read carefully pages 18 to 23 and answer the following questions:

1. In which direction do the particles vibrate in a longitudinal wave?
2. Why does an ultrasonic wave get refracted when it travels from a plastic probe unit into a steel specimen?
3. If an incident beam produces both a refracted longitudinal and a refracted transverse wave which one has the smaller angle of refraction?
4. What type (mode) of waves is produced by an angle probe?
5. The ability to detect small reflectors (sensitivity) is increased by:
 - a) increasing the frequency
 - b) decreasing the frequency
 - c) is not related to frequency

Ultrasonic Inspection

6. The ability of an ultrasonic test system to distinguish closely spaced reflectors is known as:
 - a) sensitivity
 - b) resolution
 - c) attenuation
7. True or false?

"Beam spread is reduced by having a small ratio of wavelength to transducer size."

Guide 5

Read carefully pages 24 to 32 and answer the following questions:

1. True or false?

"The plate and weld surface must always be ground smooth prior to ultrasonic examination."
2. Why should most ultrasonic examinations of welds begin with a search of the plate with a normal probe?
3. When using an angle probe, when would it be necessary to bounce the beam off the back wall?
 - a) The beam cannot bounce off the back wall.
 - b) This technique should not be used.
 - c) To examine parts of the weld that cannot be accessed by the beam directly.
4. True or false?

"Difficulties with UT can arise when welds have backing bars due to reflections from corners, internal reflections in the bars, etc."
5. Which of the following materials requires special techniques for UT examination?
 - a) Carbon steel used in a pressure vessel.
 - b) Austenitic stainless steel.
 - c) Structural steel for bridges.
6. True or false?

"The transducer in the probe always acts as the transmitter and the receiver of the ultrasonic pulse."

Guide 6

Read carefully pages 33 to 38 and answer the following questions:

1. When working to CSA W59-M1989 to what must the ultrasonic operator be certified?
2. What is the term used to describe the degree to which the distance measured on the screen is proportional to the sound path distance in the specimen?
3. What two features of an angle probe can be calibrated or checked using the IIW block?
4. Distance calibration using an IIW block for a normal (longitudinal mode) probe requires the probe to be placed:
 - a) on the top of the block such that the beam reflects from the 1.5 mm hole
 - b) on the other edge to reflect off the curved end
 - c) on the side to reflect off the back wall
5. For the transverse mode what reflector in the IIW block is used to calibrate sensitivity according to CSA W59-1989?
6. True or false?

"Resolution cannot be checked because it is a function of the design of the equipment."
7. What is a DAC curve?

Guide 7

Read carefully pages 39 to 45 and answer the following questions:

1. How is it possible to inspect most of a weld using an angle probe?
 - a) By using a very large probe.
 - b) By placing the probe on the weld reinforcement.
 - c) By scanning from adjacent to the weld moving in and out and along the weld.
2. When determining the location of a reflector how is the sound path distance measured?

3. How would you expect the amplitude of the wave reflected from a spherical pore to vary as the direction of approach of the beam is changed?
 - a) It would rise to a maximum then decrease.
 - b) It would rise to a peak only if the probe were moved in the plane of the plate.
 - c) It would not vary significantly.
4. Which of the following would be considered planar discontinuities: porosity, lack-of-fusion, cracks, suck-back, hollow beads, thin slag lines?
5. The method for measuring the characteristic length of a reflector according to CSA W59-1989 involves:
 - a) measuring between the two locations where the amplitude reaches a peak
 - b) measuring between the two points where the indication has disappeared
 - c) measuring between the two points where the amplitude drops to 50% of its maximum value
6. Would you expect the maximum amplitude method to be an effective way to determine the size of a plate lamination using a normal probe?

Guide 8

Read carefully pages 46 to 52 and answer the following questions:

1. True or false?

"In most codes and standards the acceptance or rejection of a discontinuity is based on whether it is shown that it will cause failure."
2. When using the CSA W59-M1989 procedure how is the effect of attenuation taken into account?
 - a) By assuming a loss of 1 dB per 12.7 mm of sound path greater than 25.4 mm.
 - b) By determining the DAC curve.
 - c) Attenuation is neglected.
3. True or false?

"The indication rating (dB) is a measure of the size of the defect."

4. Would a reflector with an indication rating of 8 dB and 30 mm long found in a 20 mm thick weld with a 70° probe be acceptable for a statically loaded structure according to CSA W59-M1989?
5. When following ASME procedures, does the size of the side hole used for setting the reference level, depend on weld thickness?
6. Is a DAC curve required for ASME procedures?
7. For imperfections interpreted as lack of fusion, what is the maximum acceptable length according to ASME Section VIII Div. 1?
 - a) 20 mm.
 - b) $1/3T$ (T is weld thickness).
 - c) Unacceptable regardless of length.

ANSWERS

Guide 1

1. b)
2. a)
3. 4.5 MHz
4. Slower
5. True
6. 12 dB
7. c)

Guide 2

1. c)
2. b)
3. Quartz, lithium sulphate, lead metaniobate are mentioned on page 8
4. b)
5. Ultrasonic waves of the frequency used in inspection do not travel far in air, so good coupling between the transducer and the specimen is needed
6. False

Guide 3

1. See diagram on page 11
2. a)
3. c)
4. dB (decibels)
5. B-scan
6. On-line examination of plate for defects such as laminations in a steel mill
7. True

Guide 4

1. In the same direction as the direction of wave propagation
2. The velocity is different in the two materials
3. Transverse waves
4. Transverse waves
5. a)
6. b)
7. True

Guide 5

1. False
2. To identify plate defects such as laminations that could interfere with examination of the weld with an angle probe
3. c)
4. True
5. b)
6. False, two separate probes could be used as the transmitter and receiver

Guide 6

1. CGSB 48-GP-7M
2. Horizontal linearity
3. Exit point (index point) and angle
4. c)
5. 1.5 mm side hole
6. False
7. Distance amplitude correction curve. It is used to correct for the effects of attenuation

Guide 7

1. c)
2. From the screen if the horizontal sweep is properly calibrated
3. c)
4. Lack-of-fusion and cracks
5. c)
6. No. The maximum amplitude method requires the peak reflections to occur from the tips of the discontinuity. This is not likely if the beam strikes normal to the plane of the discontinuity.

Guide 8

1. False
2. a)
3. False
4. No
5. Yes
6. Yes
7. c)

MODULE 19

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you score less than 70% we suggest you re-study the material.

1. If an ultrasonic wave has a velocity of 5.85×10^3 m/s in steel, what is the wavelength of a wave with frequency 4 MHz.
 - a) 0.68 mm
 - b) 1.46 m
 - c) 0.000684 mm
 - d) 1.46 mm
 - e) 9.85 mm
2. The frequency of the ultrasonic wave:
 - a) is set by a knob on the equipment
 - b) depends on the transducer selected
 - c) is calibrated using an IIW block
 - d) changes as the wave enters the material
 - e) reduces as the wave travels through the material
3. To reduce the height of an indication on the screen by 50% you would turn the gain control (or attenuator) through how many dB?
 - a) 2 dB
 - b) 50 dB
 - c) 60 dB
 - d) 20 dB
 - e) 6 dB
4. An ultrasonic beam changes angle (refracts) when it travels from a plastic probe into a steel specimen because:
 - a) the wave velocity is different in steel than in plastic
 - b) the frequency is different in steel than in plastic
 - c) only transverse waves can travel in steel
 - d) the angle does not change
 - e) the amplitude is reduced by attenuation

5. If you are examining a groove weld in a plate from one surface with an angle probe, how would you examine the upper portion of the weld?
- a) Place the probe on the weld reinforcement
 - b) Move the probe as close as possible to the weld
 - c) The upper portion cannot be examined
 - d) Move the probe away from the weld so the beam bounces off the lower surface to strike the upper portion of the weld
 - e) Use a normal probe close to the edge of the weld
6. What is the first item that should be checked or calibrated on an angle probe?
- a) Wavelength
 - b) Calibration is not necessary
 - c) Angle
 - d) Linearity
 - e) Exit (index) point
7. How does the UT procedure in CSA W59-M1989 account for attenuation?
- a) A DAC curve must be established
 - b) All signals are calibrated to the 1.5 mm side hole
 - c) An attenuation factor of 1 dB per 12.7 mm of sound path greater than 25.4 mm is assumed
 - d) An attenuation factor of 1 dB per 25.4 mm of sound path is assumed
 - e) No correction for attenuation is needed
8. How could you determine whether a reflector was planar or spherical?
- a) By using the 6 dB drop method
 - b) You cannot determine which it is
 - c) By measuring the sound path distance from the screen when the probe is moved
 - d) By moving the probe so that the beam strikes the reflector from different angles and noting any change in indication amplitude
 - e) By moving the probe until maximum amplitude is obtained and comparing this to the reference level
9. What three dB values are needed to calculate the indication rating according to CSA W59-M1989 procedures?
- a) Reference level, indication level, attenuation factor
 - b) Reference level, 1.5 mm side hole level, indication level
 - c) 1.5 mm side hole level, reference level, attenuation factor
 - d) Exit point level, attenuation level, DAC
 - e) DAC, 6dB drop value, reference level

10. Some of the ways in which ASME procedures differ from CSA W59-M1989 procedures are:
- a) The ASME reference hole size does not depend on thickness but the CSA W59 does
 - b) The procedures are virtually the same
 - c) CSA W59 requires careful identification of the type of discontinuity causing the reflection whereas ASME does not
 - d) ASME requires a DAC curve and characterization of discontinuities
 - e) CSA W59 requires the operator to determine whether the discontinuity will cause failure of the weld.

THE GOODERHAM CENTRE FOR INDUSTRIAL LEARNING
Answer Sheet
Module 19

Complete the 'Answer Sheet' and compare your answer with those in the 'Test Key'. If you score less than 70% we suggest you re-study the material.

Please circle only one letter corresponding to the answer you think is correct.

Question	Answer				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer sheet below is provided in the event you wish to retest yourself.

Question	Answer				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

THE GOODERHAM CENTRE FOR INDUSTRIAL LEARNING
Test Key
Module 19

Compare your answer sheet to this key.

Question	Answer				
1	a	b	c	(d)	e
2	a	(b)	c	d	e
3	a	b	c	d	(e)
4	(a)	b	c	d	e
5	a	b	c	(d)	e
6	a	b	c	d	(e)
7	a	b	(c)	d	e
8	a	b	c	(d)	e
9	(a)	b	c	d	e
10	a	b	c	(d)	e