ASNT Level II Study Guide

Ultrasonic Testing Method

second edition

by William Spaulding

The American Society for Nondestructive Testing, Inc.

45 pgs

Published by
The American Society for Nondestructive Testing, Inc.
1711 Arlingate Lane
PO Box 28518
Columbus, OH 43228-0518

ASNT exists to create a safer world by promoting the profession and technologies of nondestructive testing.

ISBN 1-57117-097-9

Printed in the United States of America

first printing 1999
second printing with revisions 10/02

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Overview of the Study Guide

This study guide contains basic information intended to prepare a candidate for Level II ultrasonic inspection examinations. This study guide does not present all of the knowledge necessary for certification; the candidate is expected to supplement this guide with the recommended references that follow.

Following key sections of the text are "Recommended reading" boxes listing references where additional information on the subjects identified can be found.

Review questions beginning on page 29 are typical of those that could appear within a portion of the Level II General Examination. These questions also indicate references for further study and are intended to aid the candidate in determining his/her comprehension of the material.

The following acronyms are used in the Recommended reading lists and Review Questions: HB=*NDT Handbook*; PI=*Ultrasonic Testing Programmed Instruction Handbook*; CT=*Ultrasonic Testing Classroom Training Handbook*; ASM=*ASM Metals Handbook.*

Acknowledgments

The authors acknowledge the support of the AlliedSignal Aerospace NDT Network, the ASNT Technical Services Department staff, and Karta Technologies, Inc. Technical reviews were provided by Yoseph Bar-Cohen, Matt Golis and Mark Warchol.

Recommended References

Nondestructive Testing Handbook, second edition: Volume 7, *Ultrasonic Testing*

Ultrasonic Testing Programmed Instruction Handbook, PI-4-4, second edition, Volumes I-III (ASNT/General Dynamics)

Ultrasonic Testing Classroom Training Handbook, CT-6-4, second edition (ASNT/General Dynamics)

Resource Materials

ASM Metals Handbook, 9th edition, Volume 17, *Nondestructive Evaluation and Quality Control, Ultrasonic Inspection*

Recommended Practice No. SNT-TC-1A (2001)

ANSI/ASNT CP-189 (2001)*: Standard for Qualification and Certification of Nondestructive Testing Personnel*

Overview of Ultrasonic Testing

History of Ultrasonic Testing

Ultrasonic testing is a nondestructive testing method that uses high frequency (>20,000 Hz) sound waves to inspect materials for surface and subsurface discontinuities.

Scientists investigating continuous wave techniques first used high frequency acoustic waves for nondestructive testing in the 1930s. The early inspection techniques relied on the transmission of ultrasound through the part from a transmitting unit to a receiving unit, which limited inspection to parts that could be accessed on opposite sides. The level of sensitivity obtainable with these early methods allowed only the detection of discontinuities that obstructed the ultrasound transmission and in effect were relatively large.

These early limitations were overcome in the 1940s by the use of pulsed ultrasonic waves. Pulse echo inspection techniques were developed where ultrasound is both transmitted and received from the same side of the part. Pulse echo ultrasonic testing is capable of detecting small discontinuities, determining their location and depth and estimating their size. This nondestructive testing technique has continued to develop into a sophisticated, reliable and efficient inspection tool, that is sometimes integrated with imaging software and used in a variety of industrial applications.

Advantages and Limitations of Ultrasonic Testing

Ultrasonic testing is a versatile volumetric examination that is capable of usefully examining a wide range of thicknesses in many materials. For example, steel forgings up to 2 m (6 ft) in diameter and 6-7 m (18-20 ft) long are regularly tested both radially and axially, as are much smaller sections such as thin wall tubing or sheet metal 1-2 mm (0.04-0.08 in.) thick. For most ultrasonic testing applications, only one side of the object needs to be accessible and for many applications, small, portable units are available. Ultrasonic testing is not hazardous to personnel, so the only safety precautions necessary are those practiced with any electrical equipment. A particularly useful feature of the method is its ability to measure quite accurately the depth location of discontinuities from the test surface.

A limitation of the method is that it is not always reliable for detection of surface and near surface discontinuities. Very small parts, and those with irregular shapes or rough surfaces, small radii, large grain size, or inhomogenieties may be difficult or impossible to test. Precise lateral (side-to-side) location and accurate sizing of discontinuities is often not possible. Identification of the type of discontinuity found is usually very subjective, requires extensive experience and is frequently debatable. Often, other methods such as electromagnetic testing, radiographic testing, liquid penetrant testing, or magnetic particle testing are often used in conjunction with ultrasonic testing to overcome these limitations.

Principles of Ultrasonic Testing

This section describes the basic elements of ultrasonic testing including the basic properties of acoustic waves and an overview of wave modes and search units.

Generation and Characteristics of Ultrasound

Ultrasound is usually generated by using electromechanical transducers called piezoelectric materials. These materials deform when subjected to an electric potential or voltage. If the potential alternates from positive to negative, the piezoelectric material expands when subjected to one polarity and contracts when the polarity is reversed. Therefore, alternating electric current may be converted into mechanical vibrations. The opposite effect also applies, that is mechanical vibrations imposed on a piezoelectric material cause the material to generate alternating electric voltages. Therefore, a transducer may act as both a generator and a detector of sound.

Acoustic Waves

When a molecule is displaced from its position of equilibrium within a material, it exerts a force on adjoining molecules and transmits its motion or energy to them before returning to its steady state position. In this manner, acoustic waves (including ultrasound) are transmitted away from the original source. The transmission of acoustic waves is similar to the action that occurs when a stone is dropped into water and the ripples spread out in all directions. Although the wave (and its associated energy) travels away from the source point, there is no net transport of water. The wave peaks and troughs correspond to maximum upward and downward displacements of the water molecules from the steady water level.

The simplest ultrasound wave is a continuous wave in which the molecules are continuously displaced back-and-forth in a repetitive way. Each repetition of the molecule displacement is 1 cycle. The frequency of the continuous wave ultrasound wave is the number of cycles a molecule goes through in 1 s and is measured in cycles per second (cps), or hertz (1 Hz is equal to 1 cps).

Velocity, Wavelength and Frequency

Velocity is the distance traveled by the ultrasound in a unit of time and it is measured in meters per second (m/s) or inches per second (in./s). Wavelength is the distance between two molecules that are experiencing the same displacement in consecutive cycles, as shown in Figure 1.1.

The mathematical relationship of these characteristics is defined in Equation 1.

$$\lambda = \frac{V}{f} \qquad \textbf{Eq. 1}$$

where:

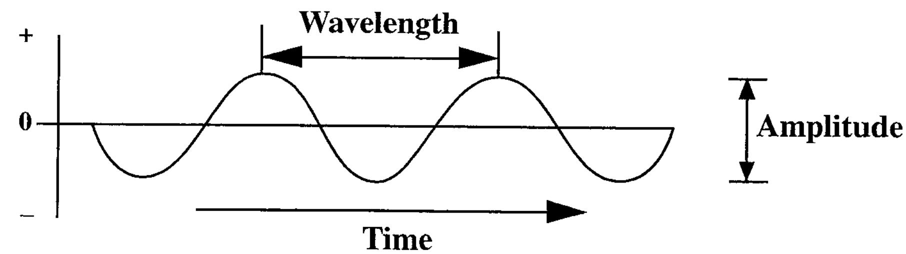
V = velocity
f = frequency
λ = wavelength

The velocity of ultrasonic waves depends on the density and the elastic constants of the test object material. It is usually independent of frequency (except for some special cases such as lamb waves which will be discussed later).

As illustrated in Equation 1, any change in frequency results in a corresponding change in wavelength – as the frequency increases, the wavelength decreases, and conversely, as frequency decreases, wavelength increases.

Like ordinary, audible sound waves, ultrasonic waves can bend around obstacles that are small compared to the wavelength of the ultrasound. Therefore, frequency selection is of prime importance because even under favorable conditions, discontinuities must have at least one dimension that is greater than or equal to $1/2\lambda$ in order to be detected. The best frequency to use for a specific inspection is a compromise between the smaller discontinuity size that can be detected with smaller

Figure 1.1: Sound wave



wavelengths and the greater depth of penetration obtained with lower frequencies. Frequencies that are commonly used for inspecting various product forms are listed in Table 1.1.

Amplitude and Energy

The amplitude of the ultrasound wave is the maximum displacement of the molecules from their position of equilibrium. The energy of the ultrasound wave is proportional to the square of the amplitude. Relative changes in ultrasound energy are measured in decibels, which is a logarithmic scale. An increase of 6 dB in the acoustic energy will double the signal amplitude on the display, a 100% increase, while a 40 dB increase will raise the amplitude 100 times.

Table 1.1: Test frequency for various product forms

Product Form	Test Frequency
Castings	200 kHz-5MHz
Forged/rolled materials (i.e., sheet, plate, bar, and forgings)	1-5 MHz
Drawn/extruded materials (i.e., pipe, tube, bar and rod)	2-10 MHz
Welds	1-5 MHz
Composites/ceramics	10-50 MHz

Types of Waves (Modes)

Ultrasound can propagate in different vibrational modes, which differ in the direction(s) of particle displacement relative to the direction of wave propagation. Longitudinal, shear, surface (rayleigh) and plate (lamb) waves are frequently used ultrasonic wave modes.

Longitudinal Waves

Longitudinal waves (also called L-waves, compressional-waves, or p-waves) have a molecular (particle) motion or displacement that is parallel to the direction of wave propagation. A snapshot of the material would show regions of lower and higher density alternating in the propagation direction as molecules pull and push the molecule in front of them. This wave is similar to the wave obtained with a long coil spring when one end is moved sharply back-and-forth along the axis of the spring. These waves are the easiest to generate and detect, and are the only type that can be propagated in liquids, gases and solids. In most ultrasonic testing applications, the ultrasound energy originates as longitudinal waves, which are converted to other modes if needed for the particular test application.

Shear Waves

Shear waves (transverse waves) have a molecule displacement that is perpendicular to the direction of propagation. [Both horizontal and vertical shear waves (SH and SV) are recognized, but they are beyond the scope of this guide.] When molecules in a plane perpendicular to the wave propagation move sideways, this sliding motion is transferred to the next plane of molecules through a shear force. This wave penetrates appreciable distances only in solids (it may penetrate a short distance in highly viscous liquids). Shear wave velocity is approximately half of the velocity for a longitudinal wave in the same material. As a result, shear waves have about half the wavelength and twice the sensitivity of longitudinal waves having the same frequency.

Surface Waves

Surface (rayleigh) waves have an elliptical wave motion and propagate along the surface of the test material. They are generally considered to have a depth of penetration into the material of approximately one wavelength. Therefore, they are useful for detecting surface and near surface discontinuities, but not for deeper discontinuities. Surface waves are very sensitive to surface discontinuities, surface contaminants (for example, grease, paint or scale) and uneven distribution of the couplant.

Lamb Waves

Lamb waves (plate waves) can propagate in platelike objects if the frequency, material thickness and beam entry angle are properly related to each other. They differ from surface waves and shear waves in that the entire part vibrates as the wave propagates parallel to the surface. Unlike surface waves, they are not readily absorbed by couplants. However, they are not widely used because there is no regular relationship between discontinuity size and response – each application requires development.

Propagation of Ultrasound

Beam Spread

Because of a fundamental physical phenomenon called diffraction, the ultrasonic beam gradually spreads out as it propagates, becoming broader as it gets farther from the transducer. Because no energy is being added as the beam propagates, the spreading out decreases the intensity of the beam. The farther the beam travels, the less intense it becomes.

Near Field (Fresnel)/Far Field (Fraunhofer)

For a simple, nonfocused search unit, as the beam travels away from the search unit, it develops zones that have different characteristics. One is called the near field (Fresnel zone) and the other is the far field (Fraunhofer zone).

In the near field, phase reinforcement and cancellation causes the beam energy to vary irregularly with location within the beam. As a result, in this region, the amplitude of an indication from a reflector is not related to the size of the reflector. While often unavoidable, the near field region is not preferred for inspection.

When the wavelength is small relative to the transducer diameter, the length of the near field increases with the search unit diameter and frequency, according to the following equation:

$$N_0 = \frac{D^2}{4\lambda} \qquad \textbf{Eq. 2}$$

where:
N_0 = the near field length
D = the diameter of the transducer
λ = the wavelength of the ultrasound

In the far field, the beam spreads at a constant angle (in a cone shape, for circular transducers) and the ultrasound energy decreases in a monotonic manner with distance from the search unit. Therefore, the amplitude of an echo from a reflector in the far field is related to the reflector size. For this reason, it is desirable to perform the inspection in the far field of the search unit whenever possible.

It is useful to know the beam width at any point in order to determine what region of the test object is being scanned. In the far field, this can be calculated from the transducer diameter and the ultrasound frequency. In general, the beam spread angle decreases with the search unit diameter and frequency approximately according to Equation 3

$$\sin \gamma = \frac{1.22\lambda}{D} \qquad \textbf{Eq. 3}$$

where:
γ = beam angle in degrees
λ = wavelength of the ultrasound
D = diameter of the transducer.

Other equations are sometimes used for specific purposes. See recommended reference *Nondestructive Testing Handbook*, second edition: Volume 7, *Ultrasonic Testing* for additional equations.

Attenuation

The reduction in energy of an ultrasound wave as it propagates through material is called attenuation, which is a material related parameter. In addition to beam spreading, scattering and absorption of the sound are the major mechanisms responsible for attenuation.

Scattering is related to the wavelength of the ultrasound and to the size and anisotropy of the metallurgical grains in the test object. Anisotropy is the condition of having different properties in different crystallographic directions within the grains. These differences in properties result in refraction, diffraction, or reflection of small amounts of the sound as it traverses grain boundaries and adjoining grains. Scattering is usually negligible when the wavelength is at least 100 times the average grain diameter, but if it is less than 10 times the grain diameter, useful testing of many materials may be problematical due to high levels of "noise" or "grass."

Absorption is caused by friction between molecules of the test material. Scattering increases with the frequency of the ultrasonic wave.

Reflection

Sound continues to travel through a medium until it reaches a boundary of that medium. At a boundary, the propagation of the sound is reflected, refracted, transmitted, or some combination of these effects. Which effects occur is dependent upon the acoustic impedances of the materials on both sides of the boundary and the angle at which the waves strike the boundary.

Acoustic impedance is defined as the product of density of the material and the velocity of the ultrasonic wave

$$Z = \rho V \qquad \textbf{Eq. 4}$$

where:
- Z = impedance
- ρ = density
- V = velocity

If the incident sound wave is traveling perpendicular to the boundary and the boundary surface is smooth, part of the sound energy is reflected and part is transmitted. The amount of sound that is reflected depends on the impedances of the materials at the boundary, as shown in Equation 5

$$R = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} \qquad \textbf{Eq. 5}$$

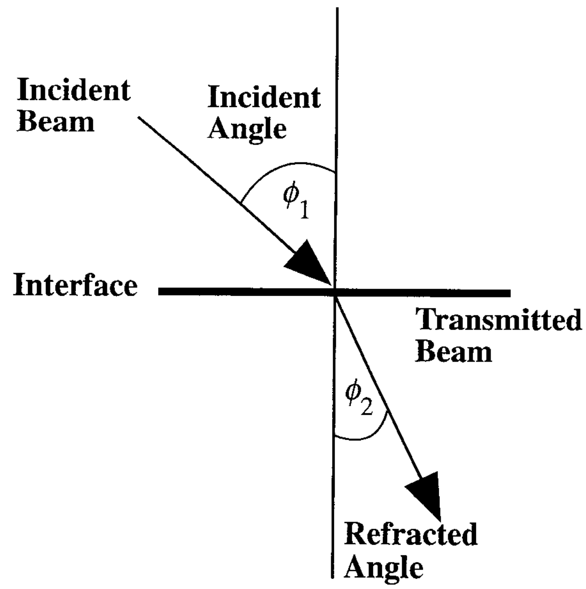
where:
- R = the reflection coefficient
- Z_1 = the impedance of material 1
- Z_2 = the impedance of material 2

If the boundary is rough, rather than smooth, some of the sound will be scattered or diffracted, which changes the amplitude of the reflected beam.

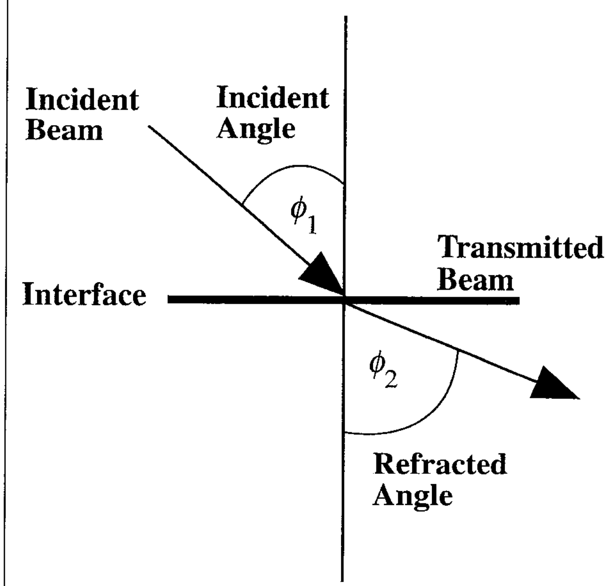
Refraction

If the incident sound wave strikes an interface at an angle of incidence other than

Figure 1.2: Angle of incidence



(a) From faster to slower material



(b) From slower to faster material

normal, the transmitted portion of the sound wave may be refracted. As shown in Figure 1.2, the transmitted beam takes a direction different from that of the incident beam. The degree of refraction that occurs is determined by the angle of incidence and the sound velocities in the materials at the boundary.

The angular relationship between the propagation direction of the incident and refracted acoustic waves depends on the respective acoustic velocities of the materials. This is expressed by Snell's law as stated in Equation 6a and 6b, where the angles are measured between the direction of propagation and a line that is perpendicular to the test surface.

$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{V_1}{V_2} \qquad \textbf{Eq. 6a}$$

$$\sin \phi_2 = V_1 \sqrt{\sin \phi_1} \qquad \textbf{Eq. 6b}$$

For example, a longitudinal wave in water ($V^1 = 1.49 \times 10^3$ m/s) striking a steel boundary ($V^2 = 5.85 \times 10^3$ m/s) at a 5 degree angle of incidence (f^1) is transmitted in the steel at a refracted angle, f^2, of 20 degrees.

Mode Conversion

Snell's law can also be applied for a mix of acoustic modes if the appropriate acoustic velocities are used. For instance, in the previous example, although the wave propagating in the first material is a longitudinal wave, part of the refracted energy will be converted to a shear wave. This is called mode conversion. Using the velocity of shear waves in steel (3.23×10^3 m/s) as V^2, a Snell's law calculation shows that a shear wave propagates in the steel at an angle of 10.9 degrees with respect to the surface perpendicular. This shear wave will be in addition to the refracted longitudinal wave (that is, both will be present).

Mode conversion can also occur in the case of reflected energy and Snell's law can be used to find the angle of the mode converted wave reflected from the interface. For example, if a longitudinal wave is incident from steel to water with an angle of 70 degrees, two waves will be reflected – one will be a longitudinal wave also at 70 degrees and the other will be a mode converted shear wave with an angle of 31.3 degrees.

The angle of the refracted beam increases with respect to the incident beam when the second material has a greater acoustic velocity than the first material and decreases when the second material has a has lower acoustic velocity. In the first case, if the incident angle is continuously increased, at a certain point the refracted angle will be 90 degrees. For larger angles, the phenomenon of total internal reflection occurs, where no ultrasound penetrates the second material. The incident angle for this condition is called the critical angle. If the second material is a solid, two critical angles exist – a smaller angle for longitudinal waves (first critical angle) and a larger angle for shear waves (second critical angle).

Recommended reading

Subject	Reference*
history of ultrasonic testing	HB
advantages/limitations of ultrasonic testing	HB; PI Vol. III
principles of ultrasonic testing	HB
reflection/refraction	HB

*See *Introduction* for explanation of references.

Ultrasonic Testing Equipment

Ultrasonic testing equipment includes transmitters/pulsers, receivers, time base generators, power supplies, displays, probes and special circuits.

Transmitters/Pulsers

A transmitter/pulser is an electronic signal generator that imposes a short interval of high frequency alternating voltage on the transducer. The transmitter/pulser, along with the clock circuit, controls the repetition rate, pulse duration and damping of ultrasonic signals.

Clock Circuits/Time Base Generators

The clock circuit produces timed pulses, a reference voltage and a reference waveform. The clock coordinates the operation of the entire electronic system.

Repetition Rate

A control available in many ultrasonic testing instruments is the repetition rate, which determines the number of times per second that a pulse is transmitted. Other instruments tie the repetition rate to the range control so that the repetition rate is preset for each choice of coarse range. Higher repetition rates provide a brighter display and can provide better discontinuity detection for high speed, automated scans. However, if the repetition rate is too high, a new pulse will be transmitted before the arrival of the echoes from prior pulses, resulting in ghost or “wraparound” signals.

Pulse Duration

Pulse duration is the length of time the pulser is imposing an alternating voltage on the transducer, as determined by the clock circuit. The longer the pulse duration, the greater the transmitted energy and the larger the dead zone, which reduces near surface resolution. A longer pulse limits the precision in time measurements and gives reduced resolution. It would be difficult to discriminate between two reflectors that are closer together in depth (time) than the length of the pulse.

Receivers (High Frequency Pulse Amplifiers)

The receiver electronically amplifies the signals returned from the test object to the receiving transducer and modifies these signals into a form suitable for display. The output from the receiver (after amplification) is a signal directly related to the intensity of the ultrasonic wave striking the receiving transducer. The bandwidth of the amplifier affects the resolution and sensitivity of the ultrasonic test, as will be discussed later.

Power Supplies

Power supply circuits provide the current for all functions of the ultrasonic instrument. These circuits are usually energized by conventional 115 V or 230 V alternating current in the case of stationary units. Portable ultrasonic instruments can also be powered by batteries contained within the unit.

Displays

Ultrasonic data is displayed in either video or radio frequency mode. In radio frequency, the cycles in each pulse are shown on the screen. In video mode, only a rectified envelope of the pulse is shown. Most ultrasonic testing instruments use an analog video display on a cathode ray tube, which is basically an oscilloscope. The horizontal deflection (sweep) voltages are synchronized, by the clock circuit, with pulses from the signal generator. The vertical deflection voltages are provided by the amplifier output signal.

Sweep/Gain Circuits

In an analog instrument, the sweep circuit is little more than a sawtooth voltage applied to a pair of horizontal deflection plates. When the voltage increases, the electron beam is driven across the screen. When the voltage drops, the beam starts again based on the clock signal.

Sweep Delay

The sweep delay shifts the time line without expanding or contracting it. The operator uses the sweep delay to move the signal horizontally and to fix the origin to a desired time or depth. For example, during immersion testing a long delay is generally used when starting the display at the test surface of the object because the signal from this surface arrives after a relatively long time-of-flight through the water.

Sweep Length

The sweep length determines the total time (depth) shown in the display. This control lets the operator fix the horizontal scale for the desired number of distance units per display division (for example, 5 mm/division).

Gain

The gain control determines the electronic amplification factor and therefore the displayed amplitude of the signal peaks. Gain control is generally calibrated in decibels. During standardization, the operator selects the gain so that the reference signals have the required amplitude.

A Scan Displays

In an A Scan system, the amplitudes of the ultrasonic signals are displayed as a function of the time-of-flight through the material, as shown in Figure 1.3. Peak 1 is the transmission pulse, peak 2 could be a discontinuity and peak 3 could be a reflection from the back wall. If the ultrasound propagates along a single homogenous material, and does not change acoustic modes, its velocity is constant. Therefore, the distance (time) between signals is proportional to the distance that separates the sources of the signals. The vertical height of the display is proportional to the amplitude of the ultrasound.

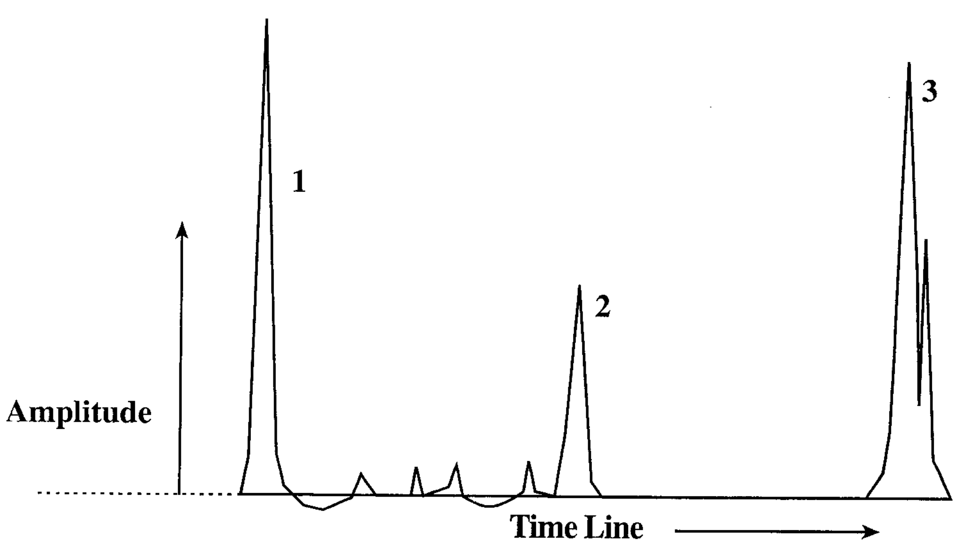
B Scan Displays

The B Scan data presentation is a cross sectional view of the test object. One axis of the display shows the position of the search probe along the surface while the other axis shows the distance from the surface to the echo. The amplitude of the received echoes is indicated by the brightness (or color) of the display. The front and back surfaces of the object are profiled on the display. The position, orientation and depth of a discontinuity along the cross section are displayed in profile as shown in Figure 1.4.

C Scan Displays

C Scan data presentation provides a plan view of the test object as shown in Figure 1.5. A gated area or "depth window" is selected so that only echoes arriving within the time frame corresponding to the depth of interest are displayed. The display presents a projection of the shape of the discontinuities found within

Figure 1.3: A Scan display – (1) front surface pulse signal, (2) discontinuity signal, and (3) back reflection signal



the depth window and the intensity or color of the display indicates the reflection strength. These displays are often printed on paper and kept as a permanent record. Many systems allow the signal to be gathered digitally, displayed on a computer screen and stored on disk for later printing. These computerized imaging systems are used to process and enhance ultrasonic testing signals, which are presented in a color form with a lookup scale that allows interpretation of the displayed data as shown in Figure 1.6. Quantitative analysis of the size, depth, or other characteristics of a discontinuity can be made using various options of the computer software.

Probes/Search Units

As discussed earlier, the generation and detection of ultrasonic waves involves the use of electromechanical transducers. Some common transducer materials used in ultrasonic probes or search units are listed in Table 1.2 together with their advantages and disadvantages. Most transducers today are based on some form of polarized ceramic such as lead zirconate titanate. Quartz, the primary material used in search units in the 1940s, is rarely used today because of its low efficiency.

Types of Probes

The most widely used types of probes are straight beam and angle beam contact probes, and flat and focused immersion probes. Various special application probes include dual element, delay line and surface wave probes.

Contact Probes

Straight beam probes generate a longitudinal wave ultrasonic beam in the test object at an angle of 90 degrees to the test surface.

Angle beam probes generate an ultrasonic beam in the test object at an angle of less than 90 degrees to the material surface. Angle beam probes usually consist of a longitudinal wave, straight beam probe with a wedge shaped plastic contact shoe that causes the beam to strike the test surface at an angle. As discussed earlier, Snell's law refraction at the wedge/part interface will then generate a mode converted shear wave within the test object.

Because a refracted longitudinal wave may also be produced in the object, and having two beams present simultaneously would be confusing to interpret, most angle beam probes are designed so that the incident angle is between the first and second critical angle. This ensures that the longitudinal wave suffers total internal reflection and only the shear wave is transmitted in the object.

Because the refracted angles depend on the relative impedances of the shoe and the object

Figure 1.4: B Scan display

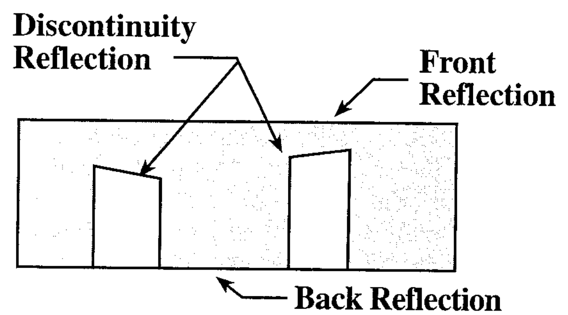


Figure 1.5: C Scan recording display

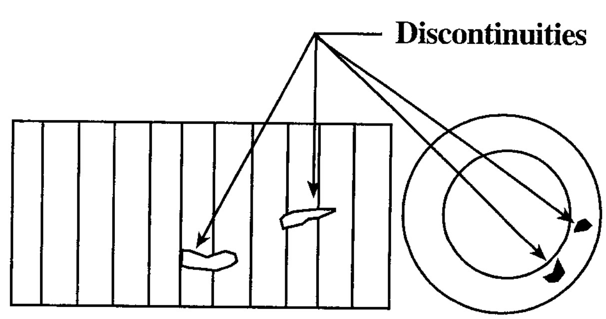
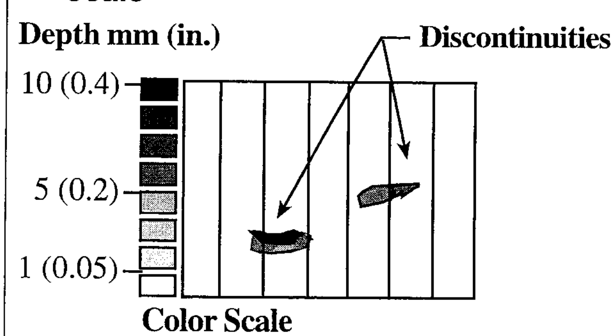


Figure 1.6: Color display density scale



material, and the impedance of the shoe or object material may not be known, it is good practice to calibrate angle beam probes on the type of material they will be used to test.

Immersion Probes (Flat and Focused)

Flat immersion probes are straight beam, longitudinal wave units. However, they can also be used for angle beam inspection by angling the probe so that the beam strikes the test surface at the desired angle of incidence. The water takes the place of the angled contact shoe described above.

Because immersion probes are immersed in water, they must be thoroughly waterproofed and well grounded.

Some immersion probes are designed to focus the beam within the test object. This is done by attaching a lens shaped shoe to the flat face of the transducer. The purpose of focusing the beam is to concentrate the ultrasound within the test object at a certain distance from the test surface, thereby increasing the test sensitivity in that region. As can be seen by Snell's law, the focal length will change if the object material is changed. (Changing the water path length also has an effect, but it is usually minor.) Cylindrically focused probes are also made, particularly for testing pipe and tube.

Probes for Special Applications

Special contact search units called dual element (dual transducer) probes can be used for thickness measurement of thin sections or for detecting discontinuities close to the test surface. These probes consist of separate transmitter and receiver elements housed in the same casing. The two elements are electrically and acoustically separated by the use of an acoustical barrier. The transducers may be mounted side-by-side for straight beam testing or stacked for angle beam testing.

Other special contact search units designed for detecting discontinuities close to the material surface have an attached stand off (delay line), which amounts to a thick soled shoe. The result is that the near field stays completely inside the probe. The delay line also has the advantage of delaying the arrival of any echo from the test object to a time after the initial (transmit) electrical pulse has decayed, which further improves near surface resolution.

Rayleigh wave (surface wave) probes are built in the same way as angle beam search units, except that the incident angle is adjusted so that the mode converted shear wave in the test object is transmitted at exactly the second critical angle. Therefore, no energy is transmitted to the bulk of the material and the

Table 1.2: Search unit materials and properties

Material	Advantages	Disadvantages
Quartz	Electrical and thermal stability; insoluble in most liquids; mechanical strength; wear resistance; uniformity; resistance to aging	Low conversion efficiency; least efficient generator
Lithium sulfate	Easily dampened; intermediate conversion efficiency; negligible mode interaction; excellent receiver	Fragile; maximum temperature of 74 °C (165 °F); soluble in water
Lead zirconate titanate	High conversion efficiency; mechanical strength; moderate temperature range	High sensitivity cannot be fully exploited because of its high acoustic impedance
Barium titanate	Mechanical strength; good generator	Depolarizes with age; efficiency changes with temperature/mode conversion
Lead metaniobate	Low mechanical damping; high tolerance to temperature	High dielectric capacitance

incident wave is mode converted to a surface wave.

Probe Design

Case

A search unit case usually consists of a metal housing that contains the transducer, electrode, backing material, grounding wires and a wear face that covers the transducer. The case provides stability and a coaxial electrical connector such as BNC, microdot, UHF, or Lemo for cable connection to the instrument.

Backing Material

Backing material provides damping of the transducer oscillations and mechanical support for the transducer. Damping is necessary to reduce the oscillations (ringing) of the transducer after the electrical/mechanical impulse ceases, in order to improve resolution. To do this, the backing material should have a high acoustic impedance to match the transducer element and be capable of absorbing the rearward directed waves that are produced. Materials such as epoxy, rubber, plastics, or composites are commonly used for backing.

Electrodes

Electrodes are primarily silver or gold deposited on the piezoelectric element. Variations in transducer performance are lessened if the deposit thickness is uniform and is less than 2 mm (0.08 in.).

Transducers (Piezoelectric Elements)

For ultrasonic frequencies greater than 200 kHz, piezoelectric materials are generally used. Common materials include quartz, lithium sulfate and polarized polycrystalline ceramics. As shown in Table 1.2, these materials vary considerably with regard to their efficiency in transmitting and receiving sound waves, their tolerance for high temperatures and their stability in water.

Wear Face

A good wear face for contact straight beam probes combines wear resistance. Thin layers of aluminum oxide, sapphire, ruby, boron, or carbides are commonly used. Probes for immersion testing seldom include a wear face, for obvious reasons.

Resolution

Resolution is the ability of an ultrasonic testing inspection system to separate the ultrasound reflections from two discontinuities that are located close together in time, depth, or distance from the probe. To obtain high resolution, it is necessary to use a highly damped probe and a wide band amplifier with flat phase curves in the vicinity of the probe frequency.

Sensitivity

Sensitivity is the ability of an ultrasonic testing inspection system to detect small discontinuities. As discussed earlier, to detect a discontinuity, the wavelength of the ultrasonic testing beam must be no more than half the smallest dimension of the discontinuity perpendicular to the beam. In addition, the signal produced by the discontinuity must be large enough to be noticeable on the display. Therefore, in general, sensitivity is increased by using higher frequencies and higher power pulses, and minimizing the beam spread, either by probe size or focusing.

Sensitivity is usually measured by the amplitude of response from artificial discontinuities in a reference block.

Special Circuits

Special circuits provide control of additional variables such as gates and distance amplitude correction/time controlled gain. Such circuits may or may not be provided on a particular instrument, but may often be purchased as options.

Gates

Gates are electronically controllable time periods that may be set up on the instrument display to correspond with specific zones within the test article. Signals appearing within the gated region may automatically operate visual or audible alarms. The gated signal may also be used to trigger a C Scan device for a permanent record. Gates have three basic controls – gate start, gate length and gate threshold (alarm level or sensitivity). Gates can be set for positive or negative operation, that is, the gate will be triggered by a positive (rising) or negative (falling) signal within the gated region. For example, a positive gate could be used to trigger on a discontinuity indication, while a negative gate might be used to trigger on a reduction of the back reflection.

Distance Amplitude Correction/Time Controlled Gain

Distance amplitude correction and time controlled gain are electronic circuits that compensate for the difference in the amplitude of signals received from different depths in a test object. Such circuits allow the operator to avoid sketching a distance amplitude correction curve on the face of the display.

Ultrasonic Testing Techniques

The most widely used ultrasonic testing techniques are the straight beam and angle beam pulse echo techniques. Table 1.3 lists some typical product applications. Other techniques for discontinuity detection include pitch catch and through transmission; these are usually used for special applications. Resonance testing is usually confined to thickness measurement and bond testing. Special processes may be used to overcome particular problems, such as testing of coarse grained materials and for measurement of crack depth.

Couplant

Regardless of the technique being used, it is usually necessary to use a couplant material between the transducer and the test object,

Table 1.3: Test technique applications for basic product forms

Product Form	Straight Beam	Angle Beam	Resonance Testing	Special Process	Reference Standard
Sheet	✓	✓	✓		
Plate	✓	✓			Side drill hole; manufactured or ASME flat bottom hole or notch
Bar, billet	✓	✓			
Tube, pipe	✓	✓			
Casting	✓			✓	Step wedge or natural
Braze, bond	✓	✓			Manufactured unbonded areas or pore
Weld	✓	✓	✓	✓	Manufactured/ASME flat bottom hole/notch, IIW
Composite	✓	✓	✓	✓	Manufactured flat bottom hole or notch

Recommended reading

Subject	Reference*
transducers	HB; PI Vol. II
display and recording equipment	HB; PI Vol. I; PI Vol. II

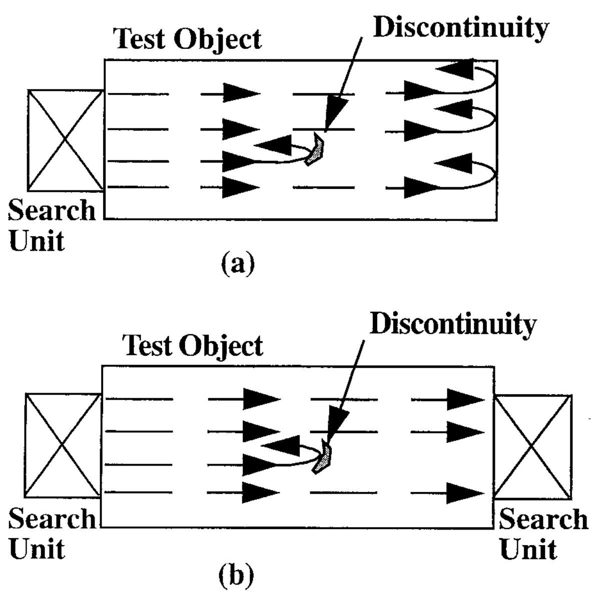
*See *Introduction* for explanation of references.

because air is a relatively poor transmitter of sound waves. There is a great impedance mismatch between air and most materials to be tested. As a result, very little of the sound generated by the transducer is able to enter the test object through a layer of air, even if that layer is very thin. Use of a couplant reduces the impedance mismatch by eliminating air and substituting a material with an impedance nearer to that of the test object. Most couplants are liquids such as water or oils, or semiliquids such as gels or greases. In some cases, it is possible to use soft, rubberlike, solid materials as couplants.

In addition to impedance matching, couplant should also:

1. conform closely to the test surface,
2. be stabile under test conditions,
3. be noncorrosive – it should not react with the object, in bulk, or in crevices of the test object, and
4. be easy to remove after testing.

Figure 1.7: Ultrasonic test techniques — (a) pulse echo technique, (b) through transmission technique



Pulse Echo Techniques

Ultrasonic testing for discontinuities is most often performed using the pulse echo technique. A single search unit is used for sending and receiving the ultrasound, as shown in Figure 1.7(a). Short, uniformly timed pulses of ultrasound are transmitted into the test object and after the pulse is transmitted, the search unit is switched to a receiving circuit. When the ultrasound waves strike a discontinuity or boundary, a portion of the energy is reflected back toward the search unit and received by it. The use of the same unit for transmission and detection has advantages in terms of simplicity of inspection, as compared to using separate transmitting and receiving units for scanning the part. Another advantage, when compared to through transmission, is that inspection can be performed with access to only one side of the test piece.

The major disadvantage of pulse echo testing is that the initial (transmission) electric pulse saturates the detection circuitry and causes the transducer to "ring"; these factors create a time period when detection of reflected signals is impossible. The region of material directly below the surface that corresponds to this time period is called the dead zone. With modern search units and electronic circuitry, the dead zone can be kept quite small. With dual or multiple transducers, the dead zone can often be eliminated.

Through Transmission Technique

The through transmission technique is also used for detecting discontinuities in an object. This technique requires two search units and access to opposite sides of the test piece. Ultrasonic waves are transmitted into the test object by a transmitting search unit. A receiving search unit is positioned on the test surface opposite the transmitting search unit to register the ultrasound passing through the object, as shown in Figure 1.7(b). The amplitude of the signal transmitted through the test object is compared to the amount of the signal transmitted through a known good area, or through a reference material. A discontinuity or region of higher attenuation reduces the transmitted energy.

Contact Testing

Contact testing uses a thin film of couplant between the search unit (or the search unit shoe) and the test object. In addition to impedance matching, it is usually desirable that the couplant act as a lubricant so the search unit slides over the test surface easily, reducing wear on the contact face of the search unit. For this reason, oil, grease, or glycerin are the most common couplants for contact tests. Maintenance of good coupling during movement of the search unit is a necessity, and requires care, particularly in the absence of relatively smooth test surfaces.

The search unit is scanned over the surface of the object, either manually or mechanically. To ensure complete testing of the desired region, it is necessary to move the search unit in such a way that successive passes overlap the previous path by a known, minimum amount. This overlap is usually specified in the test procedure, because it is necessary to account for beam spread and thereby ensure that each element of the object is searched by a suitably intense portion of the ultrasound beam.

A single search unit in pulse echo mode is most commonly used, but multiple transducers (or multiple search units) in pitch catch or through transmission mode may be used. Both straight beam and angle beam tests are common, and rayleigh or lamb waves may be used. When discontinuities near the test surface must be found, factors such as frequency, pulse length and search unit damping must be considered to optimize the near surface resolution.

Immersion Testing

In immersion testing, the test object is submerged in a liquid couplant, usually water, that contains a wetting agent and corrosion inhibitors suited to the materials to be tested. The couplant thickness amounts to a long, fluid delay line, which must be adjusted so that other signals do not interfere with reflections from within the object. As a result, it is not possible to test very thick materials. However, the technique is especially useful for testing objects with complex shapes that require several different angles of incidence of the sound beam, and maintenance of good coupling is seldom a problem. Also, continuously varying angles of incidence are possible, which allows the proper angle of incidence of the beam to be maintained while following changes in surface geometry.

Both straight beam and mode converted angle beam tests are routinely performed, but surface waves are so rapidly attenuated by the couplant as to render them useless. Focussed search units are often used in immersion testing to increase the test sensitivity in critical portions of the object. Either converging or diverging focus may be used depending on the application. In many cases, suitable focussing can completely eliminate the effects of surface roughness.

Special Ultrasonic Testing Techniques

Some special ultrasonic testing techniques that are currently being used include delta testing, tip diffraction, creeping waves, synthetic aperture focusing, ultrasonic tomography, acoustic microscopy, acoustic holography and resonance testing.

Delta testing is an indirect, pitch catch test used primarily for weld metal. It is good for detecting discontinuities but has limited ability to determine their depth or size.

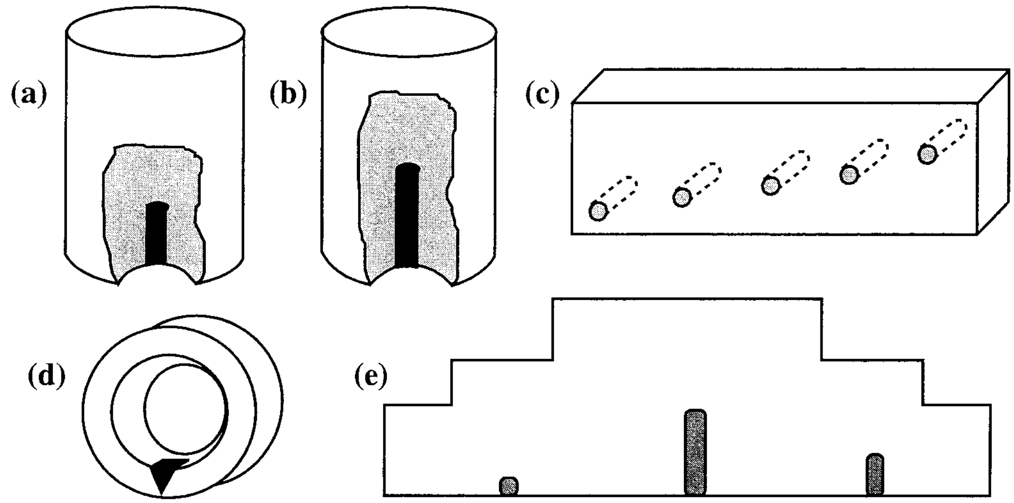
Tip diffraction is especially useful for sizing cracks, particularly the difficult depth or through wall dimension.

Creeping waves (fast surface waves) are useful for detecting small cracks at or near the surface, especially in dissimilar metal weld joints.

Synthetic aperture focusing technique and ultrasonic tomography are computer enhanced imaging techniques that detect and characterize discontinuities. Synthetic aperture focusing technique can produce images of discontinuities and tomography can be used to map stress concentrations.

Acoustic holography and microscopy are other techniques that can be used to produce

Figure 1.8: Reference blocks – (a) and (b) flat bottom hole for area and distance amplitude blocks, (c) side drilled, (d) known dimension notch, (e) flat bottom holes in block manufactured from actual part



images of discontinuities, the latter being most widely used with nonmetallics and electronic components.

Resonance testing, which is primarily used for material thickness gaging and bond testing, uses special ultrasonic testing equipment to determine the ultrasonic testing frequency at which the test material resonates.

Reference and Calibration Standards (Test Blocks)

To ensure accurate and repeatable inspection, ultrasonic testing equipment must be standardized and calibrated so that data taken by different operators are comparable and can be matched against inspection norms. This is accomplished through the use of reference and calibration standards or test blocks. Selection of a standard is determined by the testing technique, the material to be inspected and its form, the type of discontinuities to be detected, and the specification requirements.

Reference standards, such as those designed to ASTM, ASME, or AWS specifications, are used to standardize equipment responses. Blocks with flat bottom holes (Figure 1.8) are often used to standardize the amplitude of the detected signal with respect to the effective area or distance of known reflectors. Area–amplitude or distance–amplitude curves are usually constructed using such blocks. In some cases, blocks with side drilled holes are also used for such standardizations. Reference standards that vary acoustically from the test object by more than 6 dB are usually considered unacceptable for use.

Sometimes, it is preferable or required to prepare a reference standard from a piece of the same material as that to be tested, by introducing notches or holes into a sample or into the actual test object. The advantage of such a reference standard is that the test object and the standard will have the same composition, manufacturing history, surface condition and geometry. The disadvantage is that usually there will be fewer artificial reflectors and it may not be possible to manufacture the reflectors as accurately as might be done with a separate standard.

Other types of standard test blocks (and some of the above reference blocks) are used to calibrate the ultrasonic testing equipment with respect to essential variables such as sweep length, pulse energy and amplification, search unit characteristics, sensitivity, resolution and linearity. Typical calibration blocks include IIW-type blocks, DC, SC, DSC and MAB blocks. Two uses of the IIW-type blocks are shown in Figure 1.9(a) and (b).

In all cases, standards must be prepared and used in strict accordance with well designed specifications that cover the material, the fabrication and the application of the blocks.

Inspection of Material Forms

Material forms commonly inspected by ultrasonic testing include ingots, pipe and tubular products, plate and sheet, bar and rod, forgings, castings, composites, welds, bonded structures and special products.

Ingots

An ingot is refined material that is cast into a convenient shape for further processing into products such as bars, plates and tubes. These intermediate forms may be further processed by hot or cold working, or machining to form the metal into a finished product.

Ultrasonic testing is usually performed on ingots to determine the location of discontinuities, such as pipe, cracks, gross porosity, or large inclusions that must be removed before further processing. Various ultrasonic testing techniques can be used to detect these discontinuities.

Immersion testing using large search units may be used for ultrasonic testing of square, round, or rectangular cross section ingots. Pure immersion may be used for smaller ingots, while water jets provide coupling for larger ingots. The pulse echo test is the most widely used.

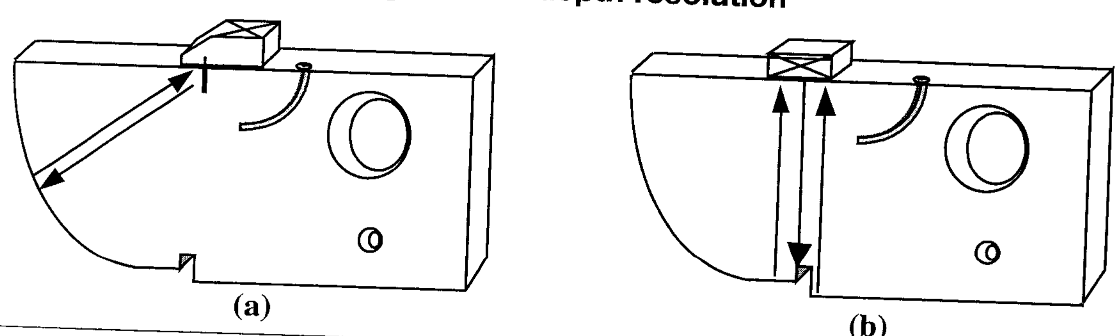
Because ingots frequently have very rough surfaces, contact testing may be difficult. However, ingots too large for immersion testing are often contact tested and may be rough machined before testing to improve the reliability of the test.

In some metals such as nickelbased alloys, coarse grain structures can cause serious attenuation problems and reduce the effectiveness of ultrasonic testing.

Pipes and Tubular Products

Pipes and other tubular products are manufactured by various methods that include

Figure 1.9: (a) IIW verification of angle beam search unit beam index point, (b) IIW determination of straight beam depth resolution



Recommended reading

Subject	Reference*
pulse echo techniques	HB
through transmission technique	HB
special ultrasonic testing techniques	HB
reference and calibration standards	HB; PI Vol. II

*See *Introduction* for explanation of references.

extrusion, swaging, drawing, forging and welding. Typical discontinuities in nonwelded tube and pipe are blisters, gouges, seams, laps and scabs. In welded products, the discontinuities are usually associated with the weld joint, and are typically of the weld type, such as cracks, lack of penetration, porosity and inclusions.

Pipes and tubes are normally tested using the shear wave technique. Immersion testing is generally used for high volume testing. When the contact technique is used, the search units usually have curved shoes/wedges to conform to the pipe or tube surface. The frequency and beam angle used are selected to ensure detection of all relevant surface and subsurface discontinuities. The waves are propagated axially and circumferentially as shown in Figure 1.10 and should be moved in both axial and circumferential directions.

Reference standards must have a wall thickness and outside diameter that are comparable to the test object. Therefore, it is common to prepare reference standards made from the material to be tested. Usually the artificial reflectors used are notches, with a depth of 3 to 5% of the wall thickness. Circumferential and axial notches are usually required and should be located a minimum of 25 mm (1 in.) from the ends of the tube and separated by a sufficient distance to avoid spurious signals (Figure 1.11). Signals from the notches are usually set between 50% and 90% of full screen height to permit a common threshold for the inspection.

Figure 1.10: Ultrasonic testing scan plan for piping and tubing

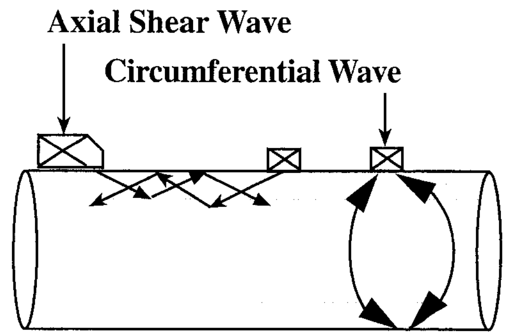


Figure 1.11: Piping/tubing reference standard

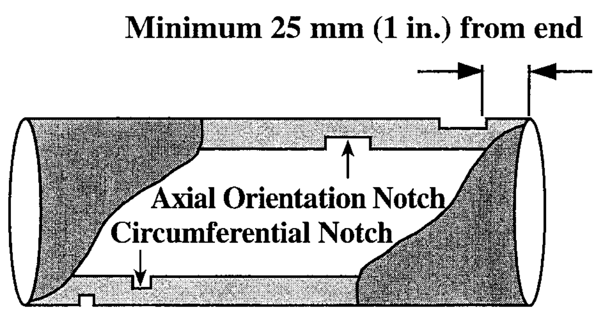


Plate and Sheet

Plate and sheet are usually manufactured by heating an ingot or billet and passing it between two rotating mechanical rollers. The rolling process is repeated with a decreasing space between the rolls until the desired thickness is obtained. Very thin sheet and foil are almost always cold rolled (without prior heating). Laminations, scabs, seams and edge cracks are the discontinuities usually sought by ultrasonic testing.

Plate may also be made by casting, but this is normally done only for metals that tend to break up if rolled. The discussion of castings on page 18 applies to cast plate.

Rolled plate and sheet is usually ultrasonically inspected using straight beam or angle beam pulse echo techniques. Both contact and immersion techniques can be used. Commonly, the material is tested by scanning from one side across the width or length of a single surface. An array of search units can be used for faster inspection and to ensure full coverage of the object. For critical applications, both straight beam and angle beam tests may be performed to increase the probability of detecting all relevant discontinuities regardless of their orientation and location.

Angle beam testing is much faster when 100% coverage is required, but laminations may remain undetected during inspection. Straight beam inspection cannot be performed on thin sheets when the front surface resolution does not allow the separation of the front surface from the back surface. A typical plate reference standard is shown in Figure 1.12.

An alternative inspection technique for suitable thicknesses of material uses lamb waves. Its use is not widespread but it is sometimes advantageous because full coverage of the width of the sheet can be obtained without moving the search unit across the sheet. However, the detected signal requires more complex signal processing because different frequency components propagate at different speeds.

Bar and Rod

Bar and rod stock are usually manufactured from billets by forging, drawing, extrusion or rolling. In most cases, the working is done at elevated temperatures. Small bars may be cold drawn from larger bars and processed through a series of progressively smaller sized dies. Typical discontinuities include cracks, laps, seams, bursts and, in large size bars, may include flakes. Straight beam and angle beam pulse echo techniques can be used for inspecting bar stock. Automated immersion systems can often reduce the time required for production inspections.

Bars are sometimes tested using a series of search units known as arrays. Figure 1.13 illustrates an array of three different search units mounted around the circumference of the bar stock. The bar is scanned by rotating it in the search units. With such systems, 100% coverage is obtained by using:

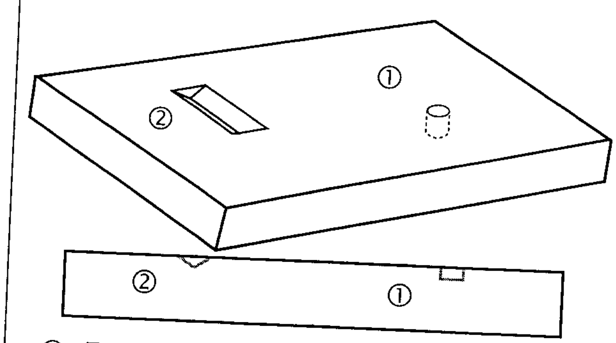
1. surface wave detection for surface discontinuities,
2. angle beam detection for near surface discontinuities, and
3. normal beam detection for deep seated discontinuities.

Forgings

Forgings are manufactured by hammering or pressing ingots or billets into open or closed dies. It may be done hot or cold, but hot forging is most common. The open die process compresses the material between two flat anvils. The closed die process compresses the metal between contoured dies that surround the finished forging. Discontinuities that may occur include cracks, bursts, flakes and laps.

Forgings are tested with contact or immersion techniques. Both straight beam and angle beam techniques are used, often on the same forging, because the test objects may be quite complex in shape. Because many forgings have rough surfaces, and the parts are frequently intended for critical service applications, it is often necessary to machine the test surface to ensure thorough test coverage and maximum sensitivity. For optimum results, the ultrasonic testing beam is generally directed at 90 degrees to the direction of the principal metal flow that occurred during the forging process.

Figure 1.12: Plate reference standard



① **Flat-bottom hole for straight-beam (longitudinal)**
② **V-notch for angle-beam (shear)**

Figure 1.13: Bar stock search unit array

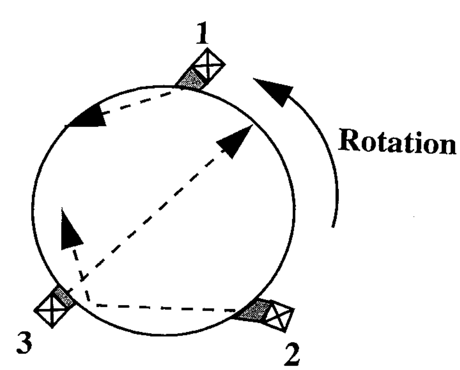
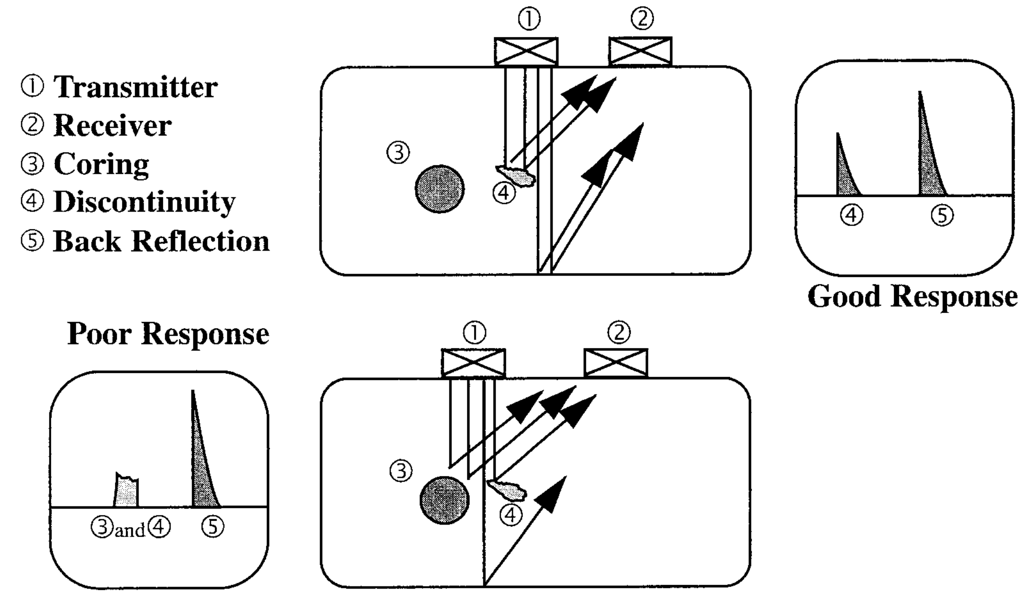


Figure 1.14: Ultrasonic testing signal response from dual search units in different positions on a casting section



Castings

Castings are produced by pouring molten metal into simple or complex shaped molds. The sand casting process is used for large parts with relatively simple shapes that do not require close tolerances or smooth finishes, or that can be readily machined to required tolerances and finishes. Small parts, intricate shapes and those requiring smooth surfaces and fine tolerances are produced by investment casting, shell casting, or permanent mold casting.

Straight beam inspections using contact, bubbler systems or immersion are used to determine wall thickness, or to assist foundry personnel in quickly locating hot tears, large shrinks and similar serious discontinuities for process control. Sometimes, dual search unit techniques are useful as shown in Figure 1.14.

One of the most useful applications of ultrasonic testing for castings is to determine the depth of subsurface discontinuities that have been detected by radiographic testing and must be removed. This application often saves a great deal of time and money by establishing how deep to grind or chip, and from which side of the casting, in order to ensure removal of each discontinuity.

Difficulties in testing castings may be caused by the complex shapes that are often encountered and the relatively rough surfaces that are common. Castings of materials whose grain size cannot be refined by heat treatment, such as austenitic steels and nickelbase alloys, may have a very coarse grain structure that can cause severe testing problems. As described earlier, very high attenuation of the beam, coupled with severe ultrasonic noise, may be encountered. This situation requires the use of an ultrasound frequency that does not provide the required test sensitivity.

Typical discontinuities associated with castings include various kinds of shrinkage cavities, cold shuts, hot tears, cracks, gas or blow holes, porosity, inclusions, core shift and unfused chaplets.

Composites

Composites are inhomogeneous materials usually consisting of layers of different materials that are bonded together or embedded in a matrix. Frequently, composites consist of layers of fiber with the fibers oriented in various directions. This situation causes major changes in ultrasonic properties in different portions of the laminate. Examples of composites that are ultrasonically tested include graphite/epoxy, glass/epoxy and plastic/epoxy. Composites may also include layers of homogeneous materials such as aluminum sheet/glass epoxy.

Discontinuities that are commonly found in composites include delaminations, voids, porosity and ply gaps. Voids and porosity are caused by outgassing of volatile chemical components in the resin that are trapped during curing. They are typically located adjacent to the fibers in the matrix.

Delaminations can result from improper curing, but most are due to impact damage, hole drilling, or other sources of excess transverse tensile, or shear stresses. Delamination can also result from foreign material inclusions that contaminate layer surfaces during the lay up process.

Inclusions may be introduced from the ply carrier film, release paper, or peel plies, and they may be difficult to resolve due to low reflectivity. Ply gaps are caused by the misalignment of composite tapes during lay up and are difficult to detect because they are filled with resin during the processing of the composite.

The strength/life of a composite is seriously affected by delaminations or ply gaps in the composite structure. These planar discontinuities can propagate under normal service loads and result in component failure.

Composites are generally tested using a straight beam or through transmission squirter technique at frequencies between 5 MHz and 25 MHz for materials less than 6 mm (0.25 in.). C Scans or digital computer imaging systems are often used for display and recording.

The integrity of the bond in adhesive bonded joints is determined by using commercially available bond testers. These machines use frequencies in the range of 2.25 to 25 MHz. The bond tester functions by transmitting a series of pulses into the material. Adhesive bond discontinuities are detected by comparing the signal amplitude of the ultrasound wave from the test piece to the ultrasound wave of a reference bond integrity standard. It is important that the reference standard resemble the test piece, especially in material composition and bond joint shape.

Reference standards are manufactured in nearly the same way as the test pieces. Delaminations and inclusions are simulated by implanting nonmetallic films in the reference standard to simulate the low reflectivity of foreign material discontinuities.

Welds

Welding processes widely used in manufacturing include electron beam, plasma arc, fusion, arc, spot and resistance welding. Wrought and cast products are often joined using welding processes. All welding techniques including automatic processes, are susceptible to discontinuities in the weld and in the adjoining base metal.

Manufacturing difficult assemblies and shapes requires the use of a variety of joint configurations. Common joint designs include variations of butt, fillet and lap joints. Many different filler metals are used depending on the metals to be joined and other variables in the process. Common weld discontinuities include hot cracks, cold cracks, porosity, inclusions, incomplete fusion, incomplete penetration, undercut and melt through.

The ultrasonic shear wave contact technique with an A Scan presentation is most often used for detecting weld discontinuities, though immersion may be used for special applications. Generally, 2 to 5 MHz is used for resolution of weld discontinuities. Higher frequencies up to 15 MHz are used on finer grained metals. An exact scan plan is necessary to ensure that all areas of the joint are evaluated. For example, in Figure 1.15, note that the ultrasound beam from the search unit in position (A) is interrogating the weld, but will not be reflected from the discontinuity. When the search unit is moved to position (B), the discontinuity will be detected.

To ensure thorough testing of welded joints, the weld and the adjoining base metal must be searched in both longitudinal and both transverse directions as shown in Figure 1.16. In addition, the base metal should be straight beam tested to protect against laminar discontinuities that would interfere with detection by the angle beam searches.

Figure 1.15: Pulse echo shear wave contact weld technique scan plan – two search unit positions

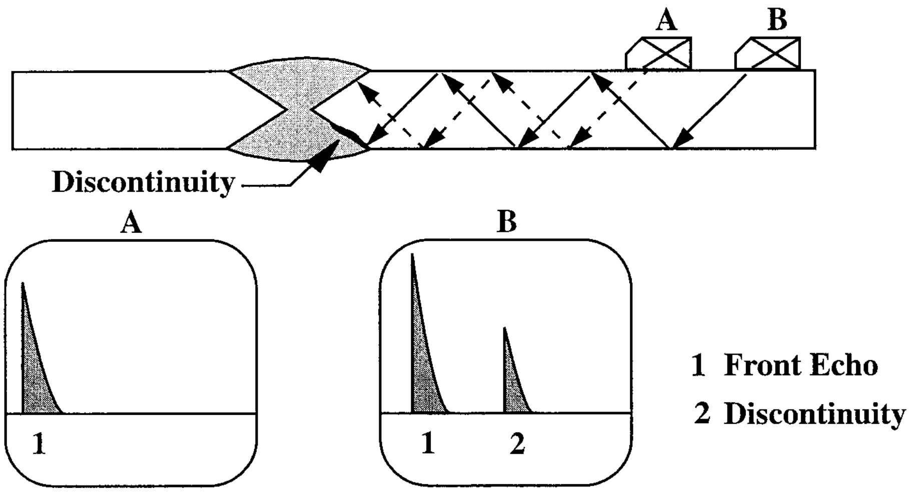
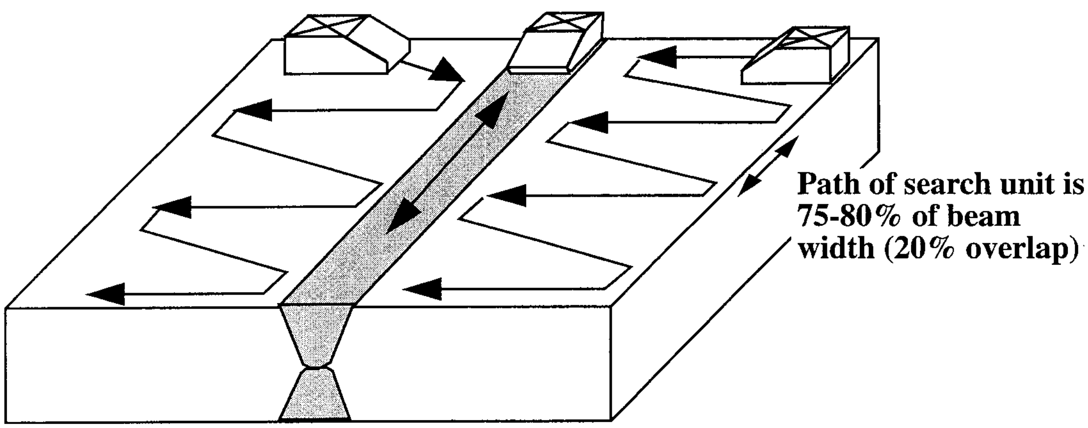
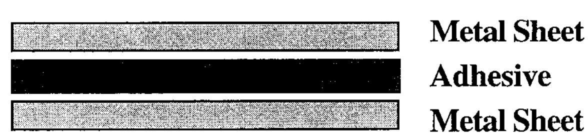


Figure 1.16: Search unit paths for full coverage of a ground flush plate weld



Bonded Structures

Figure 1.17: Adhesive bonding



Metallic brazing, soldering and adhesive bonding are common types of bonding processes. Brazing and soldering use filler metals heated to temperatures above their melting point. Adhesive bonding uses adhesive (glue) to bond adjoining parts, usually metal sheets as shown in Figure 1.17. Typical discontinuities associated with bonding processes include incomplete fill, voids, base metal erosion (brazes only), lack of bond and delamination.

Bonded joints that cannot be usefully evaluated using radiographic testing can often be examined successfully with ultrasonic testing. Straight beam testing with frequencies between 5 MHz and 15 MHz usually produces good results in braze inspections. Disbond, voids and porosity can be detected. Ultrasonic testing braze standards often consist of a sample joint with a hole drilled to the interface surface or with a synthetic void made by using stop off tape to prevent entry of the filler material into portions of the joint, as shown in Figure 1.18.

Special Products

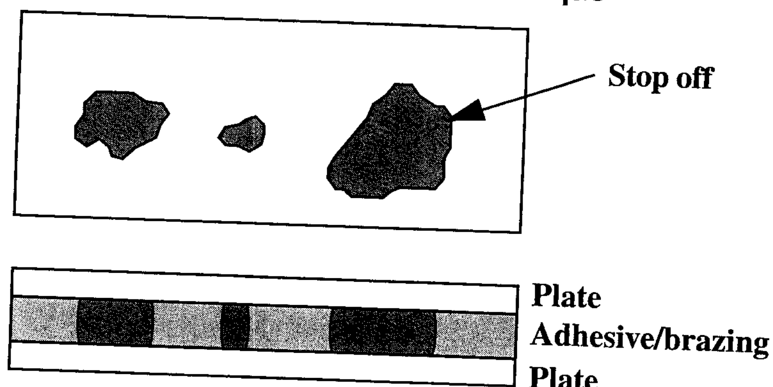
Specialized pulse echo techniques using attenuation and velocity measurements have been used successfully to examine wood, rubber, glass and ceramic materials.

Wood, especially particleboard, is examined after hot processing using an array of air coupled search units. The technique uses a frequency of 30 to 40 kHz to detect ply separations and other unfavorable discontinuities.

Rubber products are also tested with air coupled search units. Rubber used for automobile and aircraft applications is tested prior to recapping to ensure a sound rubber substrate.

Ultrasonic testing can resolve discontinuities on the order of 0.1 mm (0.004 in.) in ceramic and glass used in aerospace applications. Frequencies over 50 MHz are commonly used with focused search units. Due to the local density variations, microstructure and surface conditions, ceramic and glass materials require specialized techniques and reference standards.

Figure 1.18: Bond standard using stop off technique



Recommended reading

Subject	Reference*
ingots	HB; PI Vol. III
pipe and tubular products	HB; PI Vol. III
plate and sheet	HB; PI Vol. III
bar and rod	HB; PI Vol. III
forgings	HB; PI Vol. III
castings	HB; PI Vol. III
composites	HB; PI Vol. III
welds	HB; PI Vol. III
bonded structures	HB; PI Vol. III
special products	HB

*See *Introduction* for explanation of references.

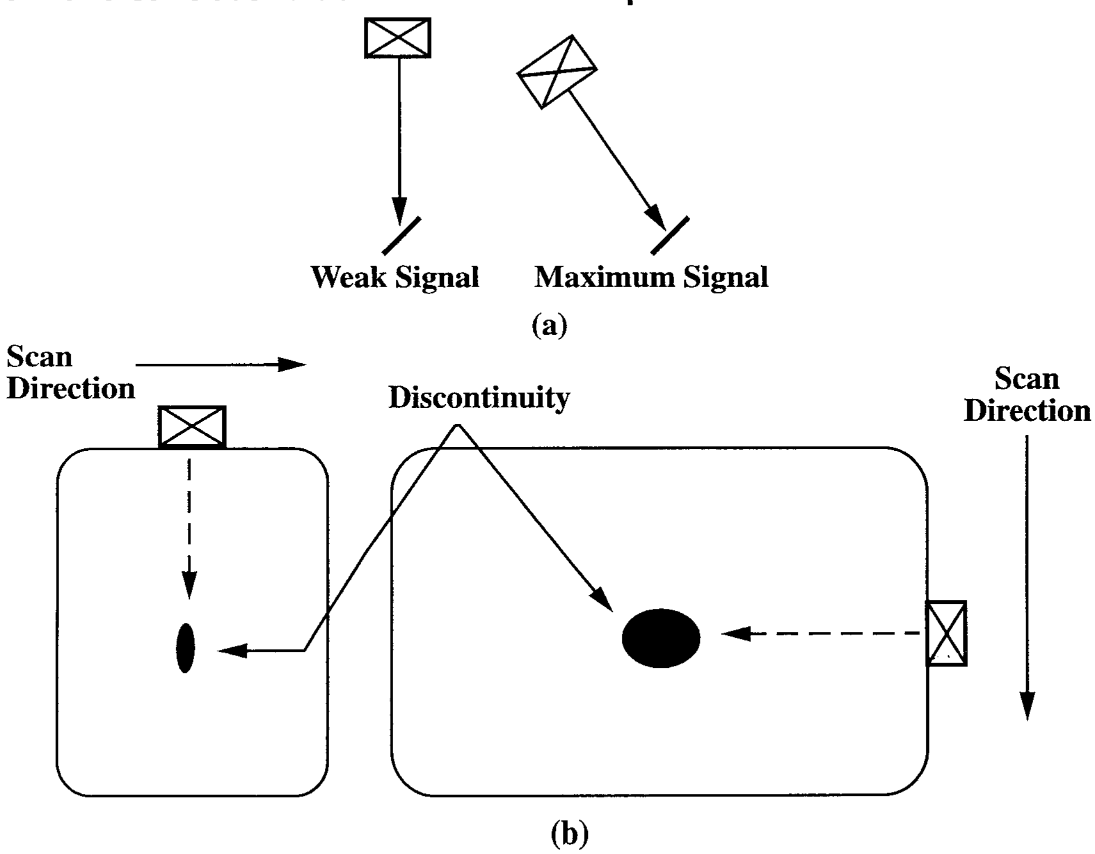
Discontinuity Detection

Ultrasonic testing inspectors must have a thorough understanding of the ultrasonic testing process and its limitations to ensure that the appropriate test parameters are used. The inspector must know the typical discontinuities that may be found in an object manufactured in a particular manner, where they may lie in the object, and at what orientation. Proper identification of the test variables and selection of the equipment increases the probability of achieving an optimum test.

To obtain adequate sensitivity, the wavelength of the ultrasound and the transmitted signal amplitude must be properly chosen. To be reflected from a discontinuity, the wavelength of the sound must be no more than twice the smallest dimension (perpendicular to the beam) of the discontinuities to be detected. Sometimes, this requirement must be balanced against the ability to penetrate the object, which may require a longer wavelength. Similarly, the signal amplitude must be sufficient to produce indications from the discontinuities sought, but not so high as to allow common acceptable material characteristics to be mistaken for rejectable discontinuities.

The size, shape, type, orientation and location of a discontinuity affects its ability to create ultrasonic reflections. Assuming that the wavelength is small enough to allow reflection from the discontinuity, spherical discontinuities such as porosity reflect the least sound while smooth, flat discontinuities reflect the most, for a given impedance mismatch. The type of discontinuity determines the impedance mismatch – voids, such as cracks or porosity, have the most mismatch while bonded inclusions and some types of segregation have the least mismatch.

Figure 1.19: (a) angulation of search unit for maximum response, (b) testing from two surfaces to obtain maximum response



If the major reflecting portion of the discontinuity is not oriented at 90 degrees to the ultrasonic beam, its maximum reflection will not be detected by a pulse echo receiver; however, it may be detectable at a location away from the transmitter. Therefore, the beam angle(s) and scan plans must be chosen to optimize the reflections from the expected discontinuities, as illustrated in Figure 1.19.

Search unit size must be selected so that the beam spread at the chosen test frequency will permit scanning the required portions of the object. Scan patterns must be chosen based on knowledge of the beam spread and regions to be inspected.

Figure 1.20 illustrates a typical immersion test setup on a forging that presents a few simple problems. A capable ultrasonic testing inspector must recognize that the thinner section (A) may require a different reference standard than the thicker section (C), and that the curved area in section (B) will require a change in incident beam angle.

A thorough understanding of the manufacturing process is required to determine such factors as the type of discontinuities associated with the process, the normal orientation of these discontinuities, and the potential for interference from conditions such as coarse grain structures. Given the many variables involved, it is usually advantageous to scan thoroughly from more than one direction, and often it is useful to use more than one wavelength or wave mode.

Figure 1.20: Immersion testing automatic carriage

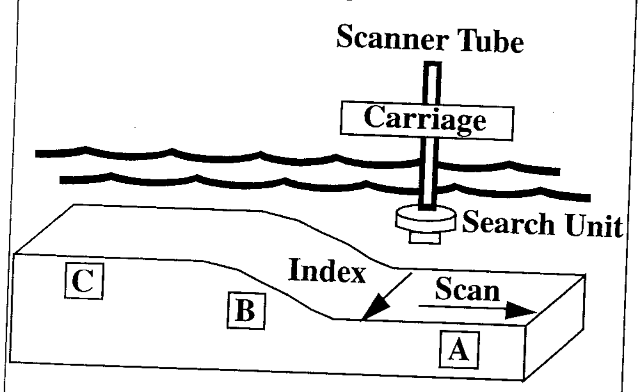
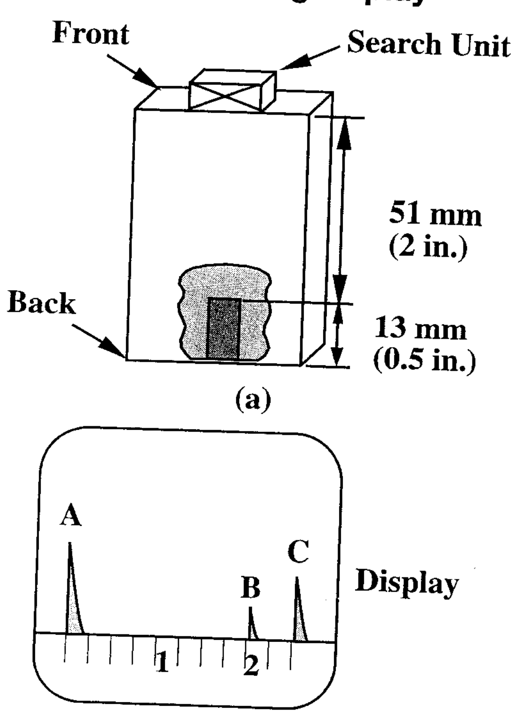


Figure 1.21: Reference block and the corresponding display



(b)

Evaluation of Indications

Estimation of Discontinuity Size

In a typical A Scan test, ultrasound waves that are reflected from the test object back to the search unit are converted into electrical pulses. Their amplitude is represented by the height of the indication on the display, while the distance (time) to the reflector is represented by the horizontal distance from the left side of the display to the indication.

Figure 1.21(a) illustrates a search unit on a reference block that is 64 mm (2.5 in.) from front to back, and contains a flat bottom hole 13 mm (0.5 in.) deep. Figure 1.21(b) represents the A Scan display of the ultrasonic test shown in Figure 1.21(a). The height of the indications represents the strength of the ultrasound reflections. The vertical scale on the display (Figure 1.22) is used to measure the signal amplitude as a percentage of screen height.

Because the discontinuity may not be oriented optimally with reference to the beam direction, the search unit must be manipulated in order to determine the maximum indication amplitude that can be obtained from the discontinuity. With straight beams, this is done by scanning forward and backward, and side–to–side, in the general area where the indication was detected. With angle beams, the search unit is scanned back and forth in a circle around the discontinuity location, while keeping the beam aimed at the discontinuity.

A first approximation of discontinuity size is usually made by comparing the maximum discontinuity indication with the indications from artificial reflectors in a reference standard. The indications that are compared must have been obtained with the same equipment and instrument settings. Because the amplitude of reflections varies with both the distance from reflector to search unit and the area of the reflector, a distance-amplitude curve constructed using reference reflectors of a single size, and an area-amplitude curve made with reference reflectors of differing sizes, are used for comparison. The discontinuity indication is compared with these curves to estimate the discontinuity size.

However, the estimated discontinuity size found in this way is almost always less than the actual discontinuity size. This is true because the discontinuity usually is not as efficient a reflector as the flat bottom holes, due to factors such as the orientation, surface roughness, impedance, or shape of the discontinuity. For example, in a large steel forging, a 51 mm × 76 mm (2 in. × 5 in.) silicate inclusion that produced an indication smaller than that from a 1.6 mm (0.06 in.) flat bottom hole at the same distance. The small reflection was primarily a result of a good impedance match between the discontinuity and the steel, because the silicate was bonded to the steel. Other examples include smooth, spherical discontinuities such as porosity, discontinuities that taper to undetectable dimensions at their ends and cracks that twist so that part of their length is edgewise to the beam.

Occasions when flat bottom hole data overestimate the discontinuity size are rare. They usually involve discontinuities that are concave relative to the incident beam and located so that they focus the reflection at the receiving search unit.

Figure 1.22: Vertical scale display

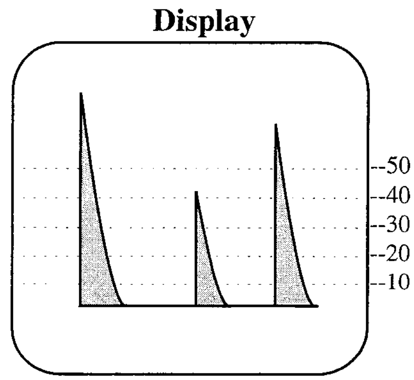
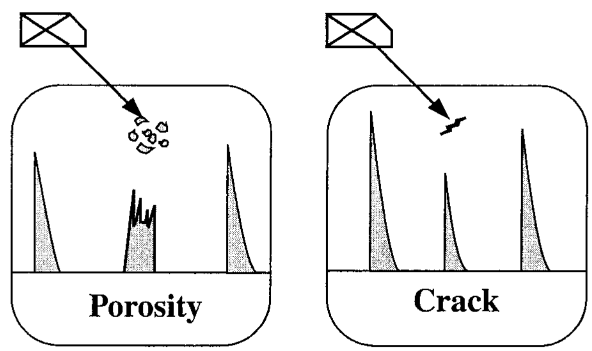


Figure 1.23: Signal display of indications



Other means of assessing discontinuity size include discontinuity mapping techniques such as signal drop (dB drop), focussed beam and special techniques such as tip diffraction.

Evaluation of Signal Patterns

The shape and width of a reflected signal on the display can suggest the type of discontinuity causing the reflection, but should not be considered 100% accurate. This information is subjective and assumes that the technique has maximized the ultrasound reflection and that the reflector has a simple, regular shape. Figure 1.23 illustrates possible signal responses from porosity and a cracktype discontinuity.

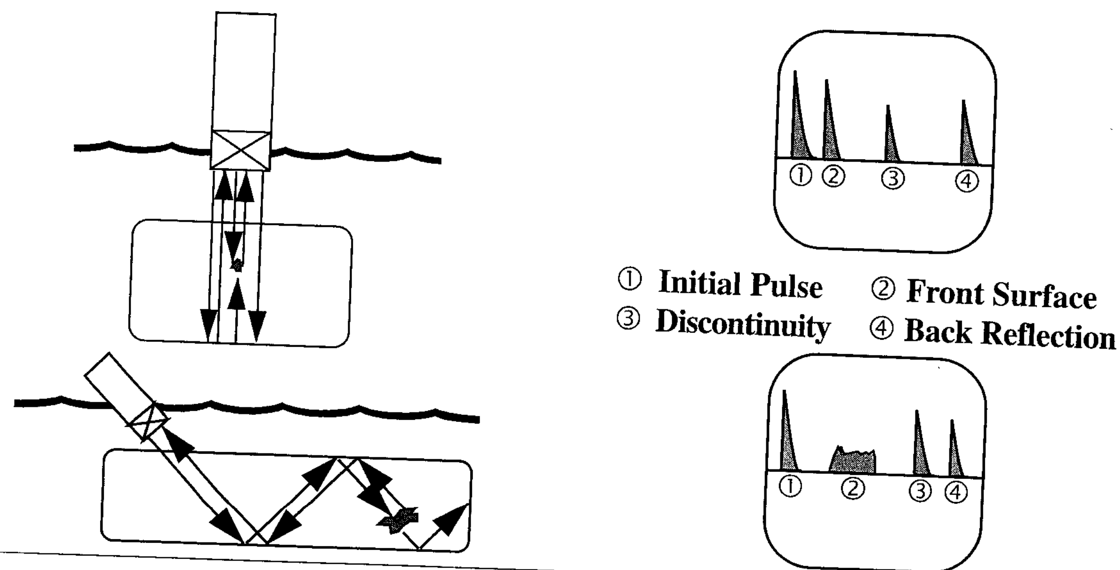
Figure 1.24 shows the displays from two immersion tests. The response from a straight beam test shows a strong front surface pulse and a back reflection. The angle beam test shows only the initial pulse, front surface and the discontinuity. If the front surface is smooth, it may provide no indication at all.

Ultrasonic Inspection Documents, Standards and Codes

Ultrasonic testing usually should be conducted in accordance with a written procedure or instruction. The ACCP defines a procedure as "a written description [of the] minimum requirements for performing a nondestructive testing method [on any object] in accordance with [the governing documents]". ACCP defines an instruction as "a description of the steps to be followed when performing a nondestructive testing technique … in conformance with [a nondestructive testing] procedure."

The procedure specifies the required minimum process parameters such as the techniques, frequencies, beam directions, scan patterns, test surfaces, personnel qualifications, reference standards, acceptance standards, etc. to be used, as determined by the codes, standards, or specifications applicable to the test objects. The governing documents used in preparing procedures may be employer or customer requirements, or ASME, ANSI,

Figure 1.24: Response display from an immersion straight beam compared to the display from an angle beam



Recommended reading

Subject	Reference*
discontinuity detection	HB
determination of discontinuity size	HB; PI Vol. II
signal patterns	HB; PI Vol. I; PI Vol. III
ultrasonic inspection documents, standards, and codes	HB; PI Vol. III

*See *Introduction* for explanation of references.

ASTM, military, or other commercial standards that apply. Ultrasonic testing procedures should generally be approved by a Level III certified in ultrasonic testing.

Instructions are derived from procedures. They specify in detail how the requirements of the procedure are to be applied to specific objects. They may include detailed scan plans, what regions are to be searched at what angles, specific surface preparation methods that are to be used, what frequency within a permitted range is to be used, what search angles are to be used in an angle beam test, what ultrasonic testing equipment must be used, etc.

Most testing requirements also specify what records of the tests are to be prepared and what details must be recorded. Even if not required, a report of the tests and the results should always be made, so the test can be repeated if corroboration of the results is desired, or if similar parts need to be tested. Commercial standards, such as those from ASTM, provide checklists of the details that should be covered in a report of ultrasonic testing work.

Review Questions

1. The type of display that never shows the entrance surface reflections is:

   a. an A Scan.
   b. a B Scan.
   c. a C Scan.
   d. an immersion scan.

   CT

2. The ultrasonic testing technique that uses two search units is the:

   a. pulse echo technique.
   b. through transmission technique.
   c. resonance technique.
   d. angle beam technique.

   CT

3. The area at the front of a test object where discontinuities may be present but cannot be detected is called the:

   a. front zone.
   b. far field.
   c. dead zone.
   d. close field.

   CT

4. Another name for rayleigh waves is:

   a. shear waves.
   b. longitudinal waves.
   c. surface waves.
   d. transverse waves.

   CT

5. Most ultrasonic testing inspections of industrial metallic components use frequencies of:

   a. 10-200 000 Hz.
   b. 200 000-1 million Hz.
   c. 1-20 million Hz.
   d. 20-100 million Hz.

   CT

6. Because the acoustic velocity in aluminum is approximately 6 mm (0.2 in.) per μs, how long does it take after the front echo to receive an echo from the back wall of a 12 mm (0.5 in.) thick aluminum block?

   a. 6 μs.
   b. 4 μs.
   c. 2 μs.
   d. 0.5 μs.

   CT; PI Vol. I

7. The wave parameter that depends only on the search unit selected is the:

   a. wavelength.
   b. velocity.
   c. frequency.
   d. attenuation.

   CT

8. The technique commonly used to detect laminations located parallel to the surface of the test object is the:

   a. lamb wave technique.
   b. straight beam technique.
   c. through transmission technique.
   d. angle beam technique.

   PI Vol. III

9. A limitation of ultrasonic testing with respect to other common inspection techniques is:

   a. its low sensitivity to small discontinuities.
   b. its limited penetration power.
   c. its high dependence on orientation of discontinuities.
   d. the need for access two surfaces of the object.

   PI Vol. III

10. The primary difference between the contact and immersion testing techniques is the use of:

a. oil couplant in immersion testing.
b. low frequency search units in immersion testing.
c. water couplant in immersion testing.
d. two search units in immersion testing.

PI Vol. III

11. An advantage of the contact technique over the immersion technique is:

a. the ability to scan irregularly shaped objects.
b. better near surface resolution of discontinuities.
c. deeper penetration power of sonic energy.
d. that higher frequencies can be used for faster scanning.

PI Vol. III

12. The use of lower test frequencies is required for:

a. forgings.
b. castings.
c. rolled shapes.
d. weldments.

PI Vol. III

13. In immersion testing, the angle formed by the ultrasound beam and a line perpendicular to the component surface:

a. decreases when it penetrates the component and increases when it leaves the component.
b. increases when it penetrates the component and decreases when it leaves the component.
c. decreases when it penetrates the component and decreases again when it leaves the component.
d. increases when it penetrates the component and increases again when it leaves the component.

PI Vol. III

14. Search units used in contact angle beam testing:

a. use a plastic wedge.
b. generate longitudinal waves at an angle smaller than 90 degrees.
c. have a constant angle for different inspected materials.
d. are always used in through transmission mode.

PI Vol. III

15. Snell's law is used to determine the relationship of:

a. frequency and velocity.
b. the angle of incidence and the angle of refraction.
c. longitudinal velocity and contact angle.
d. frequency and attenuation.

CT

16. The depth that surface waves can penetrate a material:

a. is half the material thickness.
b. is 1 wavelength.
c. is one tenth of the material thickness.
d. depends on acoustic attenuation.

CT

17. The length of the region near the face of the search unit where the intensity fluctuates depends on the:

a. test frequency.
b. diameter of the search unit.
c. velocity of sound.
d. diameter of the search unit and test frequency.

HB

18. Piezoelectric materials:

a. have low acoustic attenuation.
b. can only generate longitudinal waves.
c. convert pressure into electrical voltage.
d. have large acoustic velocities.

HB

19. Greater beam spread occurs in search units with:

 a. larger diameters.
 b. higher frequencies.
 c. unfocused lines.
 d. smaller diameters.

CT

20. A standing wave in resonance testing is established by adjusting the:

 a. test angle.
 b. test frequency.
 c. water path distance.
 d. back reflection.

HB

21. Using the through transmission technique, the quality of an object is determined by the:

 a. amount of lost sound energy.
 b. frequency of the search unit.
 c. diameter of the search unit.
 d. thickness of the test object.

CT; PI Vol. I

22. When using a straight beam technique, the greatest reflection from a narrow, linear discontinuity in a cylindrical object is provided by:

 a. sound entry at an angle to the discontinuity.
 b. sound entry perpendicular to the discontinuity.
 c. sound entry parallel to the discontinuity.
 d. a large diameter search unit to increase beam spread.

HB

23. A C Scan presentation depicts the:

 a. amplitude of the discontinuity.
 b. location of the discontinuity from the back surface.
 c. plan view of the discontinuity.
 d. depth of the discontinuity.

CT

24. When testing an object with excessive porosity, the:

 a. back reflection increases.
 b. back reflection is not affected.
 c. back reflection decreases.
 d. irregular reflections from the porosity become part of the back reflection.

25. Discontinuities in rolled product forms are most likely oriented:

 a. perpendicular to the surface.
 b. at 90 degrees to the surface.
 c. parallel to the surface.
 d. at any angle other than the rolling direction.

PI Vol. III

26. The notches in a plate reference standard for angle beam testing are placed away from the edges to:

 a. ensure that full inspection coverage is obtained.
 b. avoid reflections from the edge interfering with the notch signals.
 c. detect discontinuities oriented in any direction.
 d. ensure that the maximum resolution is obtained.

PI Vol. III

27. The proper wedge angle for contact inspection of a steel object must be selected to:

 a. ensure that the angle for longitudinal and shear waves is the same.
 b. provide similar velocities at different angles in the object.
 c. avoid producing longitudinal and shear waves at the same time and intensity.
 d. be equal to the nominal angle of the search unit.

PI Vol. III

28. A crack that is 13 mm (0.5 in.) oriented perpendicular to the sound beam is displayed:

a. only by a straight beam technique.
b. as a wide reflection with high amplitude.
c. as a sharp reflection.
d. as a wide reflection with a low amplitude.

PI Vol. III

29. The major difference between immersion and contact search units is their:

a. frequency.
b. diameter.
c. construction.
d. sensitivity.

PI Vol. III

30. The frequency of a search unit is determined by its:

a. electronics.
b. piezoelectric thickness.
c. diameter.
d. construction.

PI Vol. III

31. An advantage of a focused search unit is better resolution of smaller discontinuities at a given frequency and the:

a. ability to find discontinuities at a given depth below the test surface.
b. ability to neutralize rough back surfaces.
c. ability to maintain a narrow beam over longer distances.
d. result of a wider sound beam to detect more discontinuities.

PI Vol. III

32. Standardization is defined as:

a. indexing the search unit.
b. adjusting the amplitude of the reflector.
c. determining the proper sound entry angle.
d. adjusting the ultrasonic testing equipment to a reference standard.

PI Vol. II

33. Use the formula below to calculate the angle of refraction (ϕ_2) for a longitudinal wave passing through an interface of water-to-steel if the angle of incidence (ϕ_1) is 12 degrees. **Note:** sound velocity is 1.49 $\times 10^5$ cm/s in water (V_1) and 5.85 $\times 10^5$ cm/s in steel (V_2).

Snell's law: $$\frac{\sin\phi_1}{\sin\phi_2} = \frac{V_1}{V_2}$$

a. 31.0 degrees.
b. 54.7 degrees.
c. 78.0 degrees.
d. 81.6 degrees.

CT; PI Vol. I

34. The resolution of a search unit in a 76 mm (3 in.) thick test object is best determined by:

a. two discontinuities that are separated by more than 51 mm (2 in.) of sound metal.
b. two discontinuities that are separated by less than 6 mm (0.2 in.) of sound metal.
c. two discontinuities that are oriented at different angles to the front surface.
d. a discontinuity located 64 mm (2.5 in.) from the surface.

PI Vol. II

35. Couplant, used in contact testing, is a good conductor of sound waves and acts as a:

a. noise suppressor.
b. source to reduce surface irregularities on the test object.
c. means to reduce signal strength.
d. source to reduce reflections from edges on the test object.

PI Vol. II

36. To be effective, the flat bottom hole in a reference standard block must be flat and:

a. oriented at an angle to the test surface.
b. perpendicular to the test surface.
c. parallel to the test surface.
d. have parallel sides.

PI Vol. II

37. A set of distance amplitude blocks serve as a reference to evaluate the:

a. size of a discontinuity.
b. size of a discontinuity located at various depths in the test material.
c. distance of a discontinuity reflector from the back surface.
d. amount of beam spread using a straight beam method.

PI Vol. II

38. On tubular shapes, most ultrasonic testing is performed using:

a. longitudinal waves.
b. surface waves.
c. shear waves.
d. longitudinal and shear waves.

HB

39. A discontinuity found in a hot worked ingot that is due to high internal stresses causing a rupture within the material is called:

a. a burst.
b. a seam.
c. a lap.
d. porosity.

ASM Vol. 17

40. When fabricating a reference standard from a nonmagnetic material, the surface should be inspected by:

a. magnetic particle testing.
b. radiographic testing.
c. fluorescent penetrant testing.
d. eddy current testing.

HB

41. The best type and frequency for a search unit used to inspect the bond quality of similar metals using a straight beam technique would be:

a. focused at 2 MHz.
b. unfocused at 5 MHz.
c. focused at 20 MHz.
d. unfocused at 10 MHz.

PI Vol. III

42. When testing a plate weld using a hand scan angle beam technique, "skip distance" is the:

a. total thickness of the weld joint.
b. distance from the sound entry point to the first reflection point on the same surface.
c. "V" pattern used to scan the full length of the weld.
d. distance from the sound entry point to the first reflection from the back surface.

PI Vol. III

43. Skip distance will increase with:

a. a decrease in object thickness.
b. smaller angle probes.
c. an increase in object thickness.
d. both a and b above.

PI Vol. III

44. Wave propagation in a material as the result of sound absorption and scattering is known as:

a. diffraction.
b. attenuation.
c. reflection.
d. lamb waves.

HB

45. Small voids or nonmetallic inclusions dispersed within a forging are difficult to detect because they:

    a. are commonly found in the center of the object.
    b. are poor reflectors due to their size.
    c. are always located in the near field.
    d. cannot be detected with ultrasonic inspection.

HB

46. The velocity of shear waves is:

    a. approximately equal to half the velocity of longitudinal waves.
    b. approximately equal to the velocity of surface waves.
    c. both a and b above.
    d. independent of the material.

CT

47. A major limitation of using a low test frequency is:

    a. the limited depth of penetration.
    b. that small search probes are required.
    c. that small discontinuities are hard to detect due to a large angle of divergence.
    d. the low amplitude signals from disbonds and other flat and thin discontinuities.

CT

48. Reference standards manufactured from production parts are used because:

    a. of unique geometry and exotic metals.
    b. of the size and location of reference notches.
    c. carbon steel blocks used to test welds are not available for purchase.
    d. the cost of purchased blocks is always high.

PI Vol. II

49. Ultrasonic testing of castings is not a common practice due to their:

    a. small grain boundaries.
    b. considerable amount of porosity.
    c. large grain boundaries.
    d. irregular surface conditions.

PI Vol. III

50. The reflection amplitude of a nonmetallic inclusion is lower than the amplitude of a crack due to:

    a. variations with the reflection angle.
    b. variations in impedance.
    c. sound wave propagation.
    d. the test frequency used.

PI Vol. I

51. The mode of vibration in steel that has the greatest sound velocity is the:

    a. shear wave.
    b. surface wave.
    c. longitudinal wave.
    d. lamb wave.

CT; PI Vol. I

52. A large bandwidth search unit generates:

    a. high frequency ultrasound.
    b. short ultrasonic pulses.
    c. many ultrasonic pulses per second.
    d. high energy ultrasonic pulses.

53. When testing a course-grained object, set the pulse length control functions to:

    a. decrease the equipment resolving power.
    b. increase the level of sound energy.
    c. decrease the penetration of the sound energy.
    d. decrease the amount of noise in the object.

54. The A Scan displays information of a discontinuity's depth and its:

a. orientation.
b. shape.
c. relative size.
d. relative location to the back surface only.

PI Vol. II

55. A B Scan presentation displays:

a. a plan view of an object.
b. the amplitude of a discontinuity.
c. a cross sectional view of an object.
d. the depth of a discontinuity from the back surface.

PI Vol. I

56. Distance in an A Scan is read from:

a. top to bottom.
b. right to left.
c. the top only.
d. left to right.

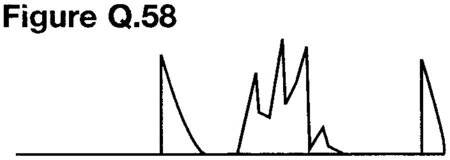
PI Vol. I

57. When using contact angle testing to locate discontinuities, an IIW reference block must be used to determine the:

a. dead zone.
b. beam exit point.
c. maximum back reflection.
d. maximum front reflection.

PI Vol. II

Figure Q.58



58. Figure Q.58 is a display from an A Scan of a IIW block using a straight beam technique. To improve the signal response, the inspector can:

a. use a reference standard made from another material.
b. use a search unit with less resolving power.
c. use a search unit with greater resolving power.
d. increase the gain.

PI Vol. II

59. Common acceptance criteria in aerospace industry specifications define the criteria by the discontinuity's:

a. location and size.
b. response level and loss of the back reflection.
c. length for single and multiple discontinuities.
d. size and depth from the back surface.

HB

60. The factor that determines the amount of reflection at the interface of two dissimilar materials is the:

a. angle of refraction at the interface.
b. difference in attenuation of the materials.
c. frequency of the ultrasound wave.
d. acoustic impedance of the material.

PI Vol. I

61. The flat bottom holes in reference standards used for immersion testing are plugged to:

a. prevent corrosion on the face of the flat bottom hole.
b. allow sound entry from either face of the standard.
c. ensure that the drilled hole stays filled with water.
d. provide a sufficient reflector for angle beam testing.

HB

62. A 305 mm (12 in.) thick, coarse grained forging requires a test frequency of:

    a. 1-2.25 MHz.
    b. 10 MHz.
    c. 15 MHz.
    d. over 20 MHz.

PI Vol. III

63. When testing complex shaped objects with tight radii or fillets, the best results are obtained using a search unit that:

    a. has a large diameter.
    b. is unfocused.
    c. is focused with a small diameter.
    d. has a low frequency.

64. The shape of a shoe that is used to obtain the maximum contact surface between the search unit and a round object is:

    a. flat.
    b. angled.
    c. curved.
    d. parallel.

PI Vol. III

Answers

1. c
2. b
3. c
4. c
5. c
6. b
7. c
8. b
9. c
10. c
11. c
12. b
13. b
14. a
15. b
16. b
17. d
18. c
19. d
20. b
21. a
22. b
23. c
24. c
25. c
26. b
27. c
28. c
29. c
30. b
31. a
32. d
33. b
34. b
35. b
36. c
37. b
38. c
39. a
40. c
41. c
42. b
43. c
44. b
45. b
46. c
47. c
48. a
49. c
50. b
51. c
52. b
53. b
54. c
55. c
56. d
57. b
58. c
59. b
60. d
61. a
62. a
63. c
64. c

Appendix
Standard Terminology for Ultrasonic Testing

This standard terminology is adapted from ASTM E 1316-98.

A Scan – A method of data presentation utilizing a horizontal base line that indicates distance, or time, and a vertical deflection from the base line, which indicates amplitude.

amplitude – The vertical pulse height of a signal, usually base-to-peak, when indicated by an A Scan presentation.

angle beam – A term used to describe an angle of incidence or refraction other than normal to the surface of the test object, as in angle beam examination, angle beam search unit, angle beam longitudinal waves and angle beam shear waves.

area amplitude response curve – A curve showing the changes in amplitude at normal incidence from planar reflectors of different areas located at equal distances from the search unit in an ultrasonic conducting medium.

attenuation – A factor that describes the decrease in ultrasound intensity with distance. Normally expressed in decibels per unit length.

attenuator – A device for altering the amplitude of an ultrasonic indication in known increments, usually decibels.

B Scan presentation – A means of ultrasonic data presentation which displays a cross section of the specimen indicating the approximate length (as detected per scan) of reflectors and their relative positions.

back reflection – Indication of the echo from the far boundary of the material under test.

back surface – The end of a reference that is opposite the entry surface.

base line – The time of flight or distance trace (horizontal) across the A Scan cathode ray tube display (for no signal condition).

beam axis – The acoustic centerline of a search unit's beam pattern as defined by the locus of points of maximum sound pressure in the far field and its extension into the near field.

beam spread – A divergence of the ultrasonic beam as the sound travels through a medium.

bottom echo – *see* **back reflection**.

bubbler – A device using a liquid stream to couple an ultrasonic beam to the test piece.

C Scan – An ultrasonic data presentation which provides a plain view of the test object and discontinuities therein.

collimator – A device for controlling the size and direction of the ultrasonic beam.

compressional wave – *see* **longitudinal wave.**

contact testing – A technique in which the search unit makes contact directly with the test piece through a thin layer of couplant.

continuous wave – A constant flow of ultrasonic waves, as opposed to pulsed.

control echo – Reference signal from a constant reflecting surface, such as a back reflection.

corner effect – The reflection of an ultrasonic beam directed at normal incidence to the line of intersection of two perpendicular planes.

couplant – A substance used between the search unit and test surface to permit or improve transmission of ultrasonic energy.

critical angle – The incident angle of the ultrasonic beam beyond which a specific refracted wave no longer exists.

cross talk – The signal leakage (acoustic or electric) across an intended acoustic or electric barrier.

crystal (see transducer) – The piezoelectric element in an ultrasonic search unit. The term is used to describe single crystal piezoelectrics as well as polycrystalline piezoelectrics, such as ferroceramics.

damping, search unit – Limiting the duration of a signal from a search unit subject to a pulsed input by electrically or mechanically decreasing the amplitude of successive cycles.

dB control – A control that adjusts the amplitude of the display signal in dB units.

dead zone – The distance in the material from the surface of the test object to the depth at which a reflector can first be resolved under specified conditions. It is determined by the characteristics of the search unit, the ultrasonic test instrumentation and the test object.

decibel (dB) – Twenty times the base ten logarithm of the ratio of two ultrasonic signal amplitudes, $dB = 20 \log_{10}$ (amplitude ratio).

delayed sweep – An A Scan or B Scan presentation in which an initial part of the time scale is not displayed.

distance amplitude compensation (electronic) – The compensation or change in receiver amplification necessary to provide equal amplitude on the display of the ultrasonic flaw detector for reflectors of equal area which are located at different depths in the material.

distance amplitude correction (swept gain, time corrected gain, time variable gain, etc.) – Electronic change of amplification to provide equal amplitude from equal reflectors at different depths.

distance amplitude response curve – A curve showing the relationship between the different distances of the amplitudes of ultrasonic response from targets of equal size in an ultrasonic transmitting medium.

distance gain size (German AVG) – Distance amplitude curves permitting prediction of reflector size compared to the response from a back surface reflection.

distance linearity range – The range of horizontal deflection in which a constant relationship exists between the incremental horizontal displacement of vertical indications on the A Scan presentation and the incremental time required for reflected waves to pass through a known length in a uniform transmission medium.

dual search unit – A search unit containing two elements, one a transmitter, the other a receiver.

dynamic range – A measure of the capability of a test system to accept input signals of varying magnitudes, given by the ratio of the maximum to minimum input signals which at constant gain will produce distortionfree outputs, having discernible changes with incremental variations in input.

echo – Indication of reflected energy.

far field – The zone of the beam where equal reflectors give exponentially decreasing amplitudes with increasing distance. Also known as the Fraunhofer zone.

focused beam – Converging energy of the sound beam at a specified distance.

Fraunhofer zone – *see* **far field.**

frequency (fundamental) – In resonance testing, the frequency at which the wave length is twice the thickness of the examined material.

frequency (inspection) – Effective ultrasonic wave frequency of the system used to inspect the material.

frequency (pulse repetition) – The number of times per second an electroacoustic search unit is excited by the pulse generator to produce a pulse of ultrasonic energy. This is also called pulse repetition rate.

Fresnel zone – *see* **near field**.

gate – An electronic means of selecting a segment of the time range for monitoring or further processing.

immersion testing – An ultrasonic examination method in which the search unit and the test part are submerged (at least locally) in a fluid, usually water.

impedance (acoustic) – A mathematical quantity used in computation of reflection characteristics at boundaries; product of wave velocity and material density.

indication – That which marks or denotes the presence of a reflector.

initial pulse – The response of the ultrasonic system display to the transmitter pulse (sometimes called main bang).

interface – The boundary between two materials.

lamb wave – A specific mode of propagation in which the two parallel boundary surfaces of the material under examination (such as a plate or the wall of a tube) establish the mode of propagation. The lamb wave can be generated only at particular values of frequency, angle of incidence and material thickness. The velocity of the wave is dependent on the mode of propagation and the product of the material thickness and the examination frequency.

linearity (amplitude) – A measure of the proportionality of the amplitude of the signal input to the receiver and the amplitude of the signal appearing on the display of the ultrasonic instrument or on an auxiliary display.

linearity (time or distance) – A measure of the proportionality of the signals appearing on the time or distance axis of the display and the input signals to the receiver from a calibrated time generator or from multiple echoes from a plate of material of known thickness.

longitudinal wave – Those waves in which the particle motion of the material is essentially in the same direction as the wave propagation.

loss of back reflection – An absence or significant reduction in the amplitude of the indication from the back surface of the part under examination.

markers – The electronically generated time pulses or other indicators that are used on the instrument display to measure distance or time.

mode – The type of ultrasonic wave propagating in the materials as characterized by the particle motion (for example, longitudinal, transverse, etc.).

mode conversion – Phenomenon by which an ultrasonic wave that is propagating in one mode can reflect or refract at an interface to form ultrasonic wave(s) of other modes.

multiple back reflections – Successive reflections from the back surface of the material under examination.

multiple reflections – Successive echoes of ultrasonic energy between two surfaces.

near field – The region of the ultrasonic beam adjacent to the transducer and having complex beam profiles. Also known as the Fresnel zone.

noise – Any undesired signal (electrical or acoustic) that tends to interfere with the reception, interpretation, or processing of the desired signal.

normal incidence (also *see* **straight beam**) – A condition in which the axis of the ultrasonic beam is perpendicular to the entry surface of the part under examination.

penetration depth – The maximum depth in a material from which usable ultrasonic information can be obtained and measured.

plate wave – *see* **lamb wave**.

probe – *see* **search unit**.

pulse – A short wave train of mechanical vibrations.

pulse echo method – An inspection method in which the presence and position of a reflector are indicated by the echo amplitude and time.

pulse length – A measure of the duration of a signal as expressed in time or number of cycles.

pulse repetition rate – *see* **frequency (pulse repetition)**.

radio frequency display – The display of an unrectified signal on the cathode ray tube or recorder.

range – The maximum sound path that is displayed.

rayleigh wave – An ultrasonic surface wave in which the particle motion is elliptical and the effective penetration is approximately one wavelength.

reference block – A block that is used both as a measurement scale and as a means of providing an ultrasonic reflection of known characteristics.

reflection – *see* **echo**.

reflector – An interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected.

reject (suppression) – A control for minimizing or eliminating low amplitude signals (electrical or material noise) so that larger signals are emphasized.

resolution – The ability of ultrasonic equipment to give simultaneous, separate indications from discontinuities having nearly the same range and lateral position with respect to the beam axis.

resonance method – A technique in which continuous ultrasonic waves are varied in frequency to identify resonant characteristics in order to discriminate some property of a part such as thickness, stiffness, or bond integrity.

saturation – A condition in which an increase in input signal produces no increase in amplitude on the display.

saturation level – *see* **vertical limit**.

scanning – The movement of a search unit relative to the test piece in order to examine a volume of the material.

scanning index – The distance the search unit is moved between scan paths after each traverse of the part.

scattering – The dispersion, deflection, or redirection of the energy in an ultrasonic beam caused by small reflectors in the material being examined.

SE probe – *see* **dual search unit (twin probe).**

search unit – An electroacoustic device used to transmit or receive ultrasonic energy, or both. The device generally consists of a nameplate, connector, case, backing, piezoelectric element, wear face, or lens, or wedge.

sensitivity – A measure of the smallest ultrasonic signal which will produce a discernible indication on the display of an ultrasonic system.

shear wave – Wave motion in which the particle motion is perpendicular to the direction of propagation.

shear wave search unit (*Y* cut quartz search unit) – A straight beam search unit used for generating and detecting shear waves.

signal-to-noise ratio – The ratio of the amplitude of an ultrasonic indication to the amplitude of the maximum background noise.

skip distance – In angle beam examination, the distance along the test surface, from sound entry point to the point at which the sound returns to the same surface. It can be considered the top surface distance of a complete vee path of sound in the test material.

straight beam – A vibrating pulse wave train traveling normal to the test surface.

suppression – *see* **reject (suppression).**

surface wave – *see* **rayleigh wave.**

sweep – The uniform and repeated movement of an electron beam across the cathode ray tube.

swept gain – *see* **distance amplitude correction.**

testing, ultrasonic – A nondestructive method of examining materials by introducing ultrasonic waves into, through or onto the surface of the article being examined and determining various attributes of the material from effects on the ultrasonic waves.

test surface – That surface of a part through which the ultrasonic energy enters or leaves the part.

through transmission technique – A test procedure in which the ultrasonic vibrations are emitted by one search unit and received by another at the opposite surface of the material examined.

transducer – An electroacoustical device for converting electrical energy into acoustical energy and vice versa. See also **crystal.**

transverse wave – *see* **shear wave.**

transverse wave – Wave motion in which the particle displacement at each point in a material is perpendicular to the direction of propagation.

true attenuation – That portion of the observed ultrasonic energy loss which is intrinsic to the medium through which the ultrasound propagates. True attenuation losses may be attributed to the basic mechanisms of absorption and scattering.

ultrasonic – Pertaining to mechanical vibrations having a frequency greater than approximately 20 000 Hz.

ultrasonic spectroscopy – Analysis of the frequency spectrum of an ultrasonic wave.

***V* path** – The angle beam path in materials starting at the search unit examination surface, through the material to the reflecting surface, continuing to the examination surface in front of the search unit, and reflection back along the same path to the search unit. The path is usually shaped like the letter V.

vertical limit – The maximum readable level of vertical indications determined either by an electrical or a physical limit of an A Scan presentation.

video presentation – Display of the rectified, and usually filtered, radio frequency signal.

water path – The distance from the transducer to the test surface in immersion or water column testing.

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

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

wedge – In ultrasonic angle beam examination by the contact method, a device used to direct ultrasonic energy into the material at an angle.