Ultrasonic Flaw Detection Tutorial

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Ultrasonic flaw detection is a powerful NDT technology and a well-established test method in many industries. However, it can seem complex to a person who has not worked with it. This tutorial provides a basic introduction to ultrasonic flaw detection, both for newcomers and for more experienced users who want a review of basic principles. It begins with a description of what ultrasonic flaw detection is and how it works, then outlines some considerations for selecting probes and instruments. It discusses instrument calibration and some basic test procedures, outlines applications, and reviews common methods for flaw sizing. A flaw detection glossary is also provided.

This tutorial covers conventional ultrasonic flaw detection. A closely related technique, phased array inspection, is discussed in our Phased Array Tutorial. Another NDT technique for flaw detection is eddy current testing, discussed in our Introduction to Eddy Current and Eddy Current Tutorial.

Please note that this tutorial is intended as an overview of ultrasonic flaw detection and is not a substitute for appropriate operator training, which may include organized classroom work and hands-on experience where required by applicable regulations and codes.

1.0 Introduction

1.1 General Introduction to Ultrasonic Testing

Early Commercialized Ultrasonic
Inspection Equipment

Handheld Thickess Gauges
Become Prevalent

Digital Flaw Detectors
Become Handheld

Advanced Automated Flaw Detection

1950 — 1960 — 1970 — 1980 — 1990 — 2000 — 2010

Early Commercialized Ultrasonic
Thickness Gauges

Early Portable Digital
Flaw Detectors

First All Digital, Handheld
Multipurpose Gauges Introduced

Phased Array Becomes Portable
and Affordable and Digital Flaw
Detectors Continue to Evolve

Ultrasonic Phased Array
Commercialized for Industrial
Applications

Ultrasonic test instruments have been used in industrial applications for more than sixty years. Since the 1940s, the laws of physics that govern the propagation of high-frequency sound waves through solid materials have been used to detect hidden cracks, voids, porosity, and other internal discontinuities in metals, composites, plastics, and ceramics, as well as to measure thickness and analyze material properties. Ultrasonic testing is completely nondestructive and safe, and it is a well-established test method in many basic manufacturing, process, and service industries, especially in applications involving welds and structural metals.

The growth of ultrasonic testing largely parallels developments in electronics and computers. Early work in Europe and the United States in the 1930s demonstrated that high-frequency sound waves would reflect from hidden flaws or material boundaries in predictable ways, producing distinctive echo patterns that could be displayed on oscilloscope screens. Sonar development during the Second World War provided further impetus for research in ultrasonics. In 1945, U.S. researcher Floyd Firestone patented an instrument he called the Supersonic Reflectoscope, which is generally regarded as the first practical commercial ultrasonic flaw detector that used the pulse/echo technique commonly employed today. It would lead to many commercial instruments introduced in the following years. Panametrics, Staveley, and Harisonic were among the leaders in the development of ultrasonic flaw detectors, thickness gauges, and transducers in the 1960s and 1970s. Today, all three are part of Olympus Corporation. In the late 1940s, researchers in Japan pioneered the use of ultrasonic testing in medical diagnostics using early B-scan equipment that provided a two-dimensional profile image of tissue layers. By the 1960s, early versions of medical scanners were being used to detect and outline tumors, gallstones, and similar conditions. In the 1970s, the introduction of precision thickness gauges brought ultrasonic testing to a wide variety of manufacturing operations that required thickness measurement of parts in situations where there was access to only one side, and corrosion gauges came into wide use to measure remaining wall thickness in metal pipes and tanks.

The latest advances in ultrasonic instruments have been based on the digital signal processing techniques and the inexpensive microprocessors that became available from the 1980s onward. This has led to the latest generation of highly reliable, portable instruments and in-line inspection systems for flaw detection, thickness gauging, and acoustic imaging.

1.2 The History of Flaw Detection

The reflection and transmission of high-frequency sound waves has long been an important tool for evaluating the integrity of welds as well as for testing structural metals, pipes and tanks, boiler tubes, railroad rails and axles, aerospace composites, and many other industrial applications. When used appropriately by a qualified operator, ultrasonic NDT is quick and reliable, usually requires no test piece preparation other than wetting with ultrasonic couplant, and has no specific safety hazards or regulatory licensing requirements associated with its use. Ultrasonic flaw detection has been a valuable quality assurance tool for many years.

As noted in the previous section, the roots of ultrasonic testing go back to early experimental work in the 1930s, and the first practical commercial ultrasonic flaw detector was introduced in 1945. Over the next twenty years, the technique gained increasing acceptance and a number of manufacturers introduced ultrasonic flaw detectors. Early instruments were big and heavy, used vacuum tubes, and required an AC power source. Solid-state circuitry permitted the introduction of smaller, battery-powered instruments in the 1960s, making ultrasonic testing more practical for field applications.

All these early instruments used analog signal processing, and like all analog instruments, they were subject to calibration drift. In 1984, Olympus predecessor Panametrics introduced the EPOCH™ 2002, the world's first field portable, all-digital flaw detector. Since then, digital instruments have become standard, providing digital stability in calibration, digital precision in measurements, onboard data logging, and the ability to share screen images, test records, and setups with computers.

While the basic technology is now familiar, ongoing developments in hardware and software have resulted in smaller and more capable instruments. Conventional ultrasonic flaw detection using small, handheld instruments with single element transducers is well established as a quality control technique in many manufacturing and service industries. In recent years there has been growing interest in phased array systems that use sophisticated technology based on multi-element probe assemblies to generate steered beams and create cross-sectional pictures similar to those in medical ultrasound imaging. These instruments are also commonly used for weld inspections.
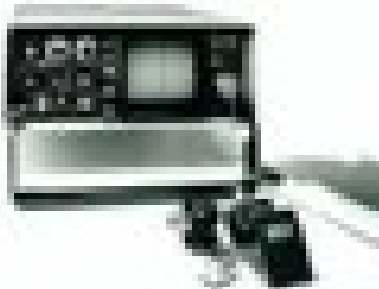
1.3 Flaw Detection Applications Overview

Ultrasonic flaw detection can potentially be applied to any standard engineering material to find hidden cracks, voids, porosity, inclusions, and similar discontinuities. While most tests involve steel and other structural metals, flaw detectors can also be used on plastics, composites, fiberglass, and ceramics. Some common applications include:

- Weld inspection—an important application for ultrasonic flaw detection
- Primary metals—beams, billets, bars, ingots, forgings, and tubular stock
- Infrastructure—bridge beams, bridge pins, railroad rails, and metal structures

- Petrochemical—pipelines, tanks, and support structures
- In-service testing—railroad wheels and axles, aircraft landing gear and engine mounts, crane booms, drive shafts, tanks and pressure vessels, and bolt testing
- Manufacturing—spot welds, braze joints, castings, and bond testing
- Composites—aerospace parts, wind turbines, automotive composites, and marine fiberglass

1.4 Types of Equipment Available

Contemporary ultrasonic flaw detectors are small, portable, microprocessor-based instruments suitable for both shop and field use. They generate and display an ultrasonic waveform that enables a trained operator to locate and categorize flaws in test pieces, often with the aid of analysis software. They typically include an ultrasonic pulser/receiver, hardware and software for signal capture and analysis, a waveform display, and a data logging module. Most contemporary instruments use digital signal processing for optimum stability and precision.

Modern flaw detectors typically capture a waveform and then perform various measurement and analysis functions on it. An internal clock is used to synchronize transducer pulses and provide distance calibration. Signal processing may be as simple generating a waveform display that shows signal amplitude versus time on a calibrated scale, or as complex as sophisticated digital processing algorithms that incorporate distance/amplitude correction and trigonometric calculations for angled sound paths. Alarm gates are often employed to monitor signal levels at selected points in the wave train to flag echoes from flaws.

The screen is normally calibrated in units of depth or distance. Multicolor displays can be used to provide interpretive assistance. Internal data loggers can be used to record full waveform and setup information associated with each test, if required for documentation purposes, or selected information like echo amplitude, depth or distance readings, or presence or absence of alarm conditions.

A special advanced category of portable ultrasonic flaw detectors is phased array instruments, which use more complex hardware with software similar to that used in medical diagnostic imaging to provide a higher level of test and interpretive capability. Instead of a single element transducer, phased arrays use probes with a large number of elements, all individually pulsed and time-delayed. Ultrasonic beams are formed by constructive and destructive interference from these multiple sources. Unlike conventional instruments, phased array systems can electronically focus, steer, and sweep the beam and then generate detailed cross-sectional images of the test piece. Phased array systems are explored in detail in the Olympus Phased Array Tutorial.

2.0 Basic Ultrasonic Theory

2.1 What is Ultrasound?
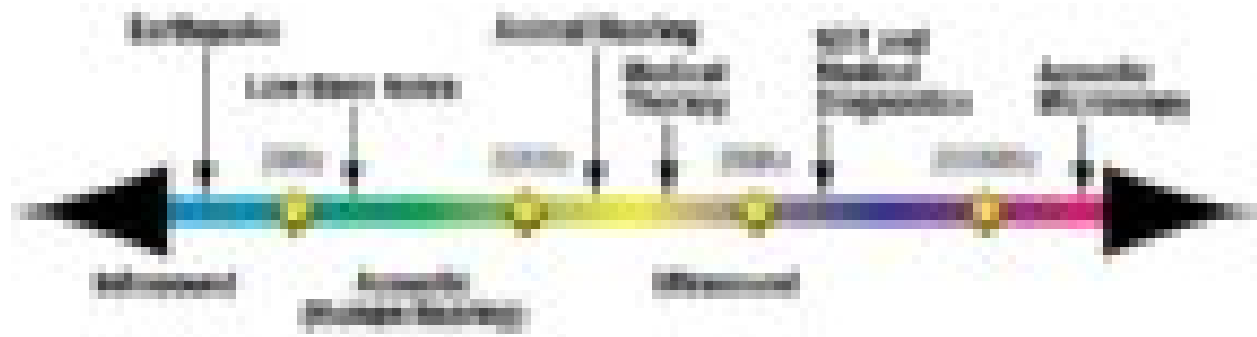
Sound waves are simply organized mechanical vibrations traveling through a medium, which may be a solid, a liquid, or a gas. This applies to both the everyday sounds that we hear and the ultrasound used for flaw detection. Sound waves will travel through a given medium at a specific speed or velocity in a predictable direction, and when they encounter a boundary with a different medium, they will be reflected or transmitted according to simple rules. This is the principle of physics that underlies ultrasonic flaw detection. In short, ultrasonic waves will reflect from cracks or other discontinuities in a test piece, so by monitoring the pattern of echoes in a part, a trained operator can identify and locate hidden internal flaws.

All sound waves oscillate at a specific frequency, or number of vibrations or cycles per second, which we experience as pitch in the familiar range of audible sound. Human hearing extends to a maximum frequency of about 20,000 cycles per second (20 KHz), while the majority of ultrasonic flaw detection applications utilize frequencies between 500,000 and 10,000,000 cycles per second (500 KHz to 10 MHz). At frequencies in the megahertz range, sound energy does not travel efficiently through air or other gasses, but it travels freely through most liquids and common engineering materials like most metals, plastics, ceramics, and composites. Sound waves in the ultrasonic range are much more directional than audible sound, and, because of their short wavelengths, they are also far more sensitive to small reflectors that lie in their path.

The speed of a sound wave varies depending on the medium it's traveling through and is affected by the medium's density and elastic properties. Different types of sound waves (see Modes of Propagation, Section 2.3) will travel at different velocities.

2.2 Generating Ultrasound (Transducers)

Single Element Transducer

Dual Element Transducer
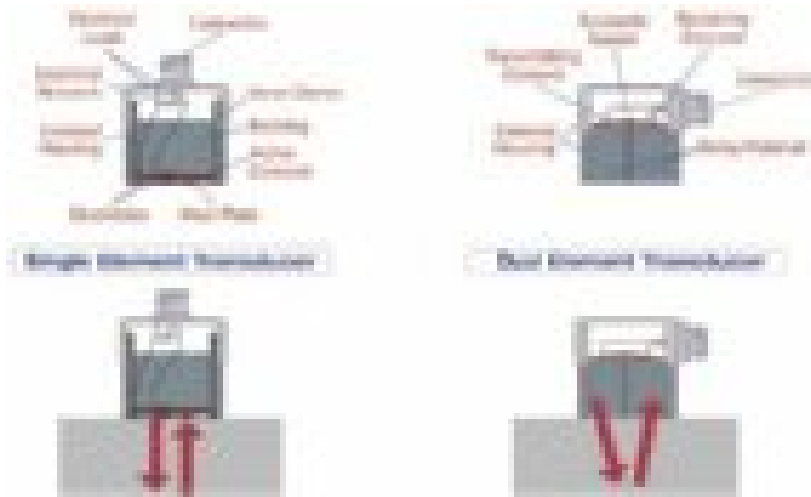
The ultrasonic waves used for flaw detection are generated and received by small probes called ultrasonic transducers, which convert electrical pulses into sound waves and sound waves into electrical energy. Transducers for flaw detection come in a wide variety of sizes, frequencies, and case styles, but most have a common internal structure.

Typically, the transducer's active element is a thin disk, square, or rectangle of piezoelectric ceramic or piezocomposite that converts electrical energy into mechanical energy (ultrasonic vibrations), and vice versa. When it is excited by an electrical pulse, it generates sound waves, and when it is vibrated by returning echoes, it generates a voltage. The active element, which is informally called the crystal, is protected by a wear plate or acoustic lens and backed

by a block of damping material that quiets the transducer after the sound pulse has been generated. This ultrasonic subassembly is mounted in a case with appropriate electrical connections. All common contact, angle beam, delay line, and immersion transducers use this basic design. Dual element transducers, commonly used in corrosion survey applications, differ in that they have separate transmitting and receiving elements separated by a sound barrier, no backing, and an integral delay line to steer and couple the sound energy, rather than a wear plate or lens.
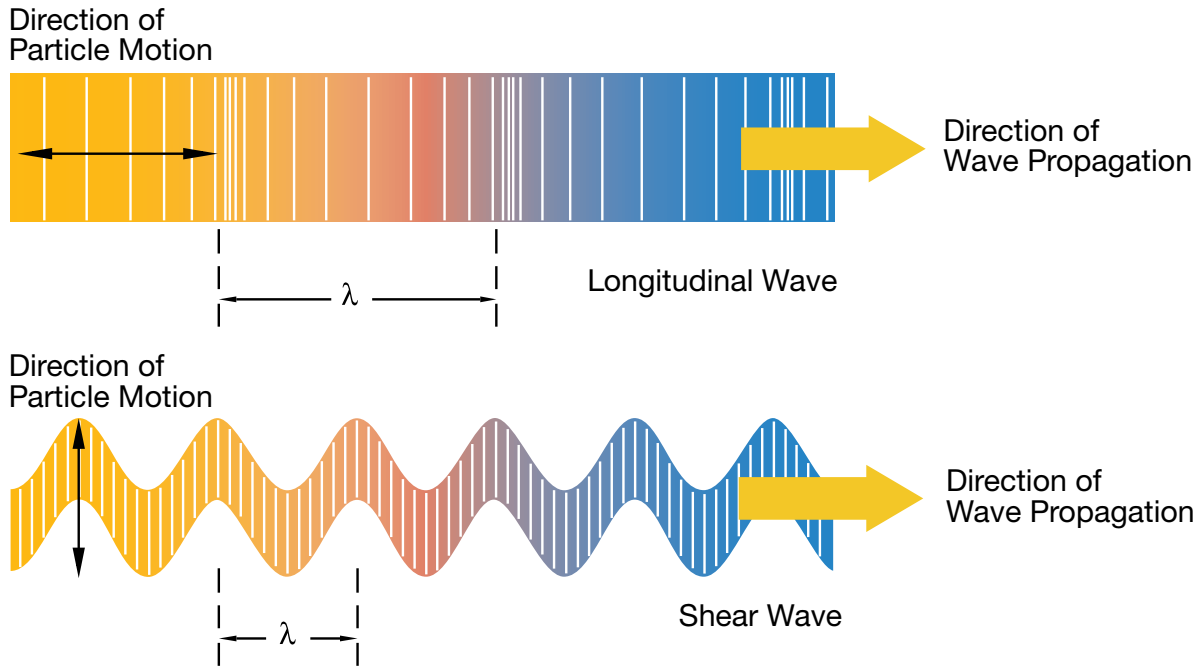
Couplants

Ultrasonic couplants are used in virtually all contact testing applications to facilitate the transmission of sound energy between the transducer and the test piece. Couplants will typically be moderately viscous, nontoxic liquids, gels, or pastes. Their use is necessary because sound energy at the ultrasonic frequencies typically used for ultrasonic NDT is not effectively transmitted through air. Even an extremely thin air gap between the transducer and the test piece will prevent efficient sound energy transmission and make conventional testing impossible.

A number of common substances such as water, motor oil, grease, and even some commercial products like hair gel can be used as ultrasonic couplants. Specialized couplants are used for high-temperature testing and cases where special chemistry such as low halogen content is required.

2.3 Wave Propagation

Sound energy used in flaw detection travels in different wave modes based on the direction of the wave and the corresponding motion of molecules in the test piece. The most commonly used modes are longitudinal waves, shear waves, and surface waves.

Direction of
Particle Motion

Direction of
Wave Propagation

λ

Longitudinal Wave

Direction of
Particle Motion

Direction of
Wave Propagation

λ

Shear Wave

Longitudinal waves: In a longitudinal wave, particle motion in the medium is parallel to the direction of the wave front. Audible sound waves are longitudinal waves. Longitudinal waves travel the fastest of the wave modes commonly used in ultrasonic NDT, approximately 5900 meters per second (0.23 inches per microsecond) in steel. Longitudinal waves may convert to shear waves through refraction or reflection, as discussed in section 2.5 below.

Shear waves: In a shear wave, particle motion is perpendicular to wave direction. Shear waves have a slower velocity and shorter wavelength than longitudinal waves of the same frequency and are used for most angle beam testing in ultrasonic flaw detection. Typical shear wave velocity in steel is approximately 3250 meters per second (0.128 inch per microsecond). Shear waves can exist in solids only, not in liquids or gasses. They can convert to longitudinal waves through reflection or refraction at a boundary.

Surface waves: Surface waves, also known as Rayleigh waves, represent an oscillating motion that travels along the surface of a test piece to a depth of one wavelength. Velocity and wavelength are similar to shear waves. Ocean waves are an example of surface waves. Surface waves can be used to detect surface-breaking cracks in a test piece.

Several additional wave modes exist but are much less commonly used in ultrasonic flaw detection. These include Lamb waves and various other forms of plate waves and guided waves that are outside the scope of this tutorial.

2.4 Beam Characteristics

Conventional single element longitudinal wave ultrasonic transducers work as a piston source of high-frequency mechanical vibrations, or sound waves. As voltage is applied, the piezoelectric transducer element (often called a crystal) deforms by compressing in the direction perpendicular to its face. When the voltage is removed, typically less than a microsecond later, the element springs back, generating the pulse of mechanical energy that comprises an ultrasonic wave. The graphic below shows a conceptualized example of how a piezoelectric element responds to a brief electrical pulse.

Piezoelectric Response to Excitation
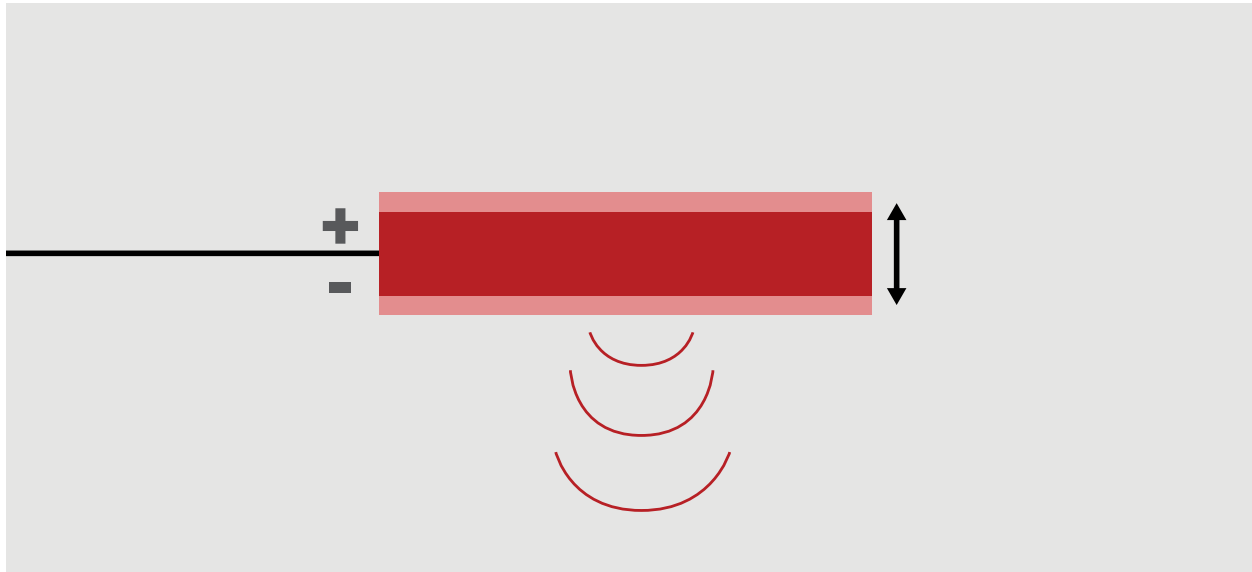
Transducers of the kind most commonly used for ultrasonic NDT will have these fundamental functional properties:

Type—The transducer will be identified according to function as a contact, delay line, angle beam, or immersion type. Inspected material characteristics such as surface roughness, temperature, and accessibility as well as the position of a defect within the material and the inspection speed will all influence the selection of transducer type.

Diameter—The diameter of the active transducer element, which is normally housed in a somewhat larger case.

Frequency—The number of wave cycles completed in one second, normally expressed in kilohertz (KHz) or megahertz (MHz). Most industrial ultrasonic testing is done in the frequency range from 500 KHz to 20 MHz, so most transducers fall within that range, although commercial transducers are available from below 50 KHz to greater than 200 MHz. Penetration increases with lower frequency, while resolution and focal sharpness increase with higher frequency.

Bandwidth—The portion of the frequency response that falls within specified amplitude limits. In this context, it should be noted that typical NDT transducers do not generate sound waves at a single pure frequency, but rather over a range of frequencies centered at the nominal frequency designation. The industry standard is to specify this bandwidth at the -6 dB (or half amplitude) point.

Waveform duration—The number of wave cycles generated by the transducer each time it is pulsed. A narrow bandwidth transducer has more cycles than a broader bandwidth transducer. Element diameter, backing material, electrical tuning, and transducer excitation method all impact waveform duration.

Sensitivity—The relationship between the amplitude of the excitation pulse and that of the echo received from a designated target.

As a working approximation, the beam from a typical unfocused disk transducer is often thought of as a column of energy originating from the active element area that expands in diameter and eventually dissipates.

In fact, the actual beam profile is complex, with pressure gradients in both the transverse and axial directions. In the beam profile illustration below, red represents areas of highest energy, while green and blue represent lower energy.

A transducer's sound field is divided into two zones, the near field and the far field. The near field is the region close to the transducer where the sound pressure goes through a series of maximums and minimums, and it ends at the last on-axis maximum at distance N from the face. Near field distance N represents the natural focus of the transducer.

FAR FIELD

N

Amplitude variations in the nearfield
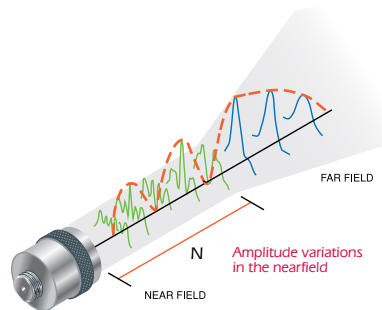
NEAR FIELD

The far field is the region beyond N where the sound pressure gradually drops to zero as the beam diameter expands and its energy dissipates. The near field distance is a function of the transducer's frequency and diameter and the sound velocity in the test medium, and it may be calculated as follows for the circular elements most commonly used in ultrasonic flaw detection:

$$N = D^2f/4c \text{ or } N = D^2/4\lambda$$

where:
N = near field length
D = element diameter
f = frequency
c = material sound velocity
λ = wavelength (c/f)

Because of the sound pressure variations within the near field, it can be difficult to accurately evaluate flaws using amplitude-based techniques (although thickness gaging within the near field is not a problem). Additionally, N represents the greatest distance at which a transducer's beam can be focused by means of either an acoustic lens or phasing techniques. Immersion transducers can be focused

with acoustic lenses to create an hourglass-shaped beam that narrows to a small focal zone and then expands. Certain types of delay line transducers can be focused as well. Beam focusing is very useful when testing small-diameter tubing or other test pieces with sharp radiuses since it concentrates sound energy in a small area and improves echo response.


TRANSDUCERS

WATER

WP

F

MP

FOCAL POINT IN WATER

FOCAL POINT IN TEST PART
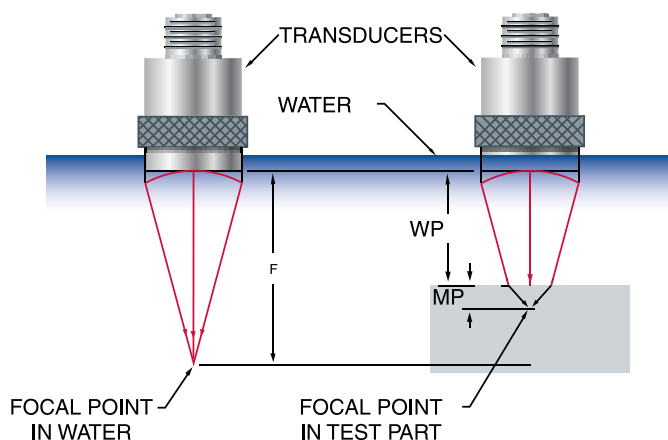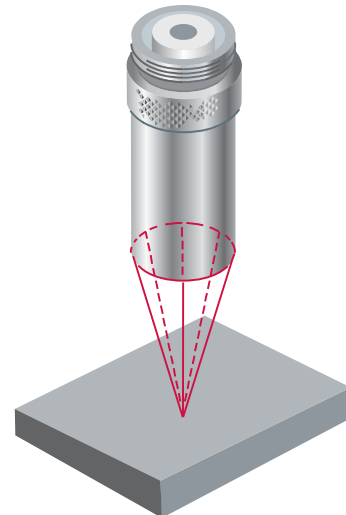
2.5 Wave Front Dynamics

Wave front formation

While a single element transducer may be thought of as a piston source, a single disk or plate pushing forward on the test medium, the wave it generates may be mathematically modeled as the sum of the waves from a very large number of point sources. This derives from Huygens' Principle, first proposed by seventeenth-century Dutch physicist Christiaan Huygens, which states that each point on an advancing wave front may be thought of as a point source that launches a new spherical wave, and that the resulting unified wave front is the sum of all these individual spherical waves.

Beam spreading

In principle, the sound wave generated by a transducer will travel in a straight line until it encounters a material boundary. What happens next is discussed below. But if the sound path length is longer than the near field distance, the beam will also increase in diameter, diverging like the beam of a spotlight. The beam spread angle of an unfocused transducer can be calculated as follows:
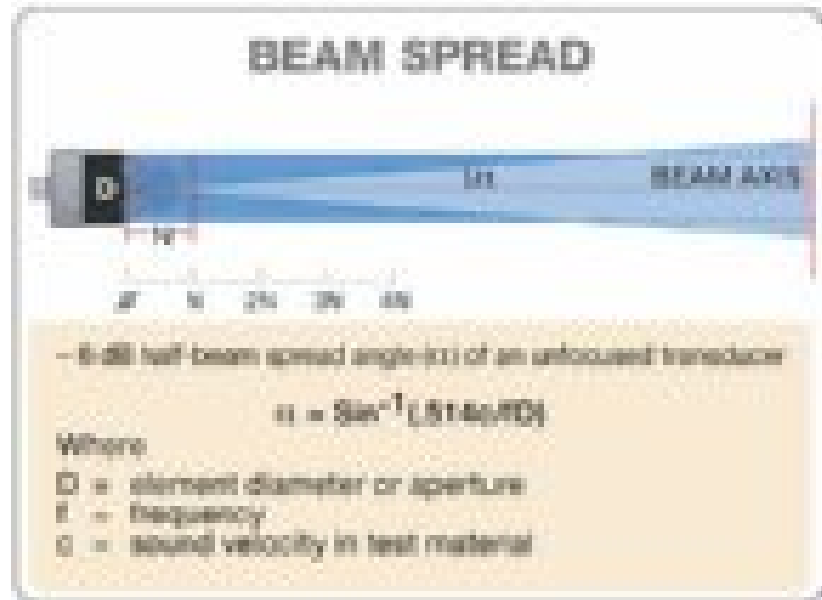
This equation shows that beam spreading increases with lower frequencies and smaller diameters. Since a large beam spread angle can cause sound energy per unit area to quickly drop with distance, effectively decreasing sensitivity to small reflectors, the echo response in some applications involving long sound paths can be improved by using higher frequency and/or larger diameter transducers.
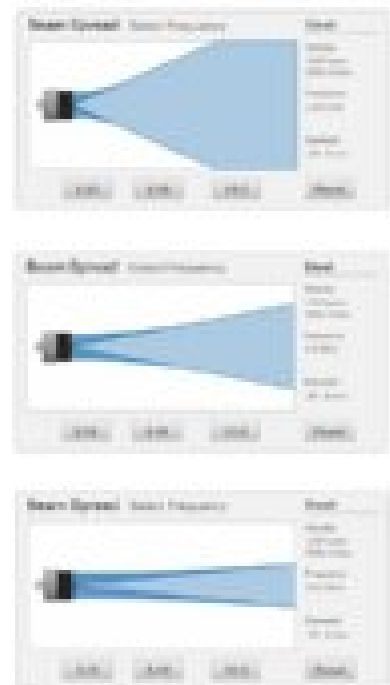
Attenuation

As it travels through a medium, the organized wave front generated by an ultrasonic transducer begins to break down due to imperfect transmission of energy through the microstructure of any material. Organized mechanical vibrations (sound waves) turn into random mechanical vibrations (heat) until the wave front is no longer detectable. This process is known as sound attenuation.

The mathematical theory of attenuation and scattering is complex. The loss of amplitude due to attenuation across a given sound path is the sum of absorption effects, which increase linearly with frequency, and scattering effects, which vary through three zones depending on the ratio of the size of grain boundaries or other scatterers to wavelength. In all cases, scattering effects increase with frequency. For a given material at a given temperature, tested at a given frequency, there will be a specific attenuation coefficient, commonly expressed in Nepers per centimeter (Np/cm). Once this attenuation coefficient is known, losses across a given sound path may be calculated according to the equation:

As a practical matter, in ultrasonic NDT applications, attenuation coefficients are normally measured rather than calculated. Higher frequencies are attenuated more rapidly than lower frequencies in any medium, so low test frequencies are usually employed in materials with high attenuation coefficients, like low-density plastics and rubber.

Reflection and transmission at a perpendicular plane boundary

When a sound wave traveling through a medium encounters a boundary with a dissimilar medium that lies perpendicular to the direction of the wave, a portion of the wave energy will be reflected straight back, and a portion will continue straight ahead. The percentage of reflection versus transmission is related to the relative acoustic impedances of the two materials, with acoustic impedance, in turn, being defined as material density multiplied by the speed of sound. The reflection coefficient at a planar boundary, the percentage of sound energy that is reflected back to the source, may be calculated as follows:


This equation illustrates that as the acoustic impedances of the two materials become more similar, the reflection coefficient decreases, and as the acoustic impedances become less similar, the reflection coefficient increases. In theory, the reflection from the boundary between two materials of the same acoustic impedance is zero, while, in the case of materials with very dissimilar acoustic impedances, as in a boundary between steel and air, the reflection coefficient approaches 100%.

Refraction and mode conversion at non-perpendicular boundaries

When a sound wave traveling through a material encounters a boundary with a different material at an angle other than zero degrees, a portion of the wave energy will be reflected forward at an angle equal to the angle of incidence. At the same time, the portion of the wave energy that is transmitted into the second material will be refracted in accordance with Snell's law, which was independently derived by at least two seventeenth-century mathematicians. Snell's law relates the sines of the incident and refracted angle to the wave velocity in each material as diagramed below.
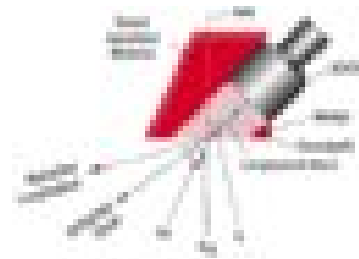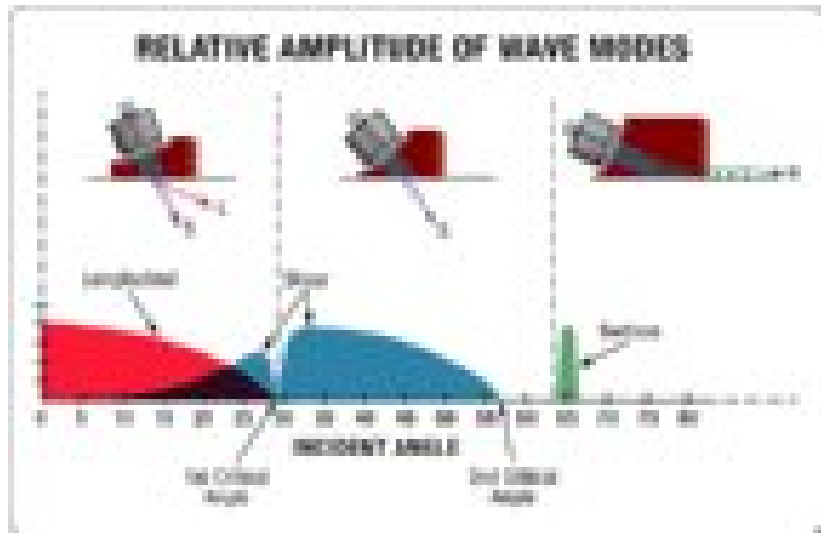
If sound velocity in the second medium is higher than that in the first, then above certain angles this bending will be accompanied by mode conversion, most commonly from a longitudinal wave mode to a shear wave mode. This is the basis of widely used angle beam inspection techniques. As the incident angle in the first (slower) medium, such as a wedge or water, increases, the angle of the refracted longitudinal wave in the second (faster) material, such as metal, will increase. As the refracted longitudinal wave angle approaches 90 degrees, a progressively greater portion of the wave energy will be converted to a lower velocity shear wave that will be refracted at the angle predicted by Snell's law. At incident angles higher than that which would create a 90-degree refracted longitudinal wave, the refracted wave exists entirely in shear mode. A still higher incident angle will result in a situation where the shear wave is theoretically refracted at 90 degrees, at which point a surface 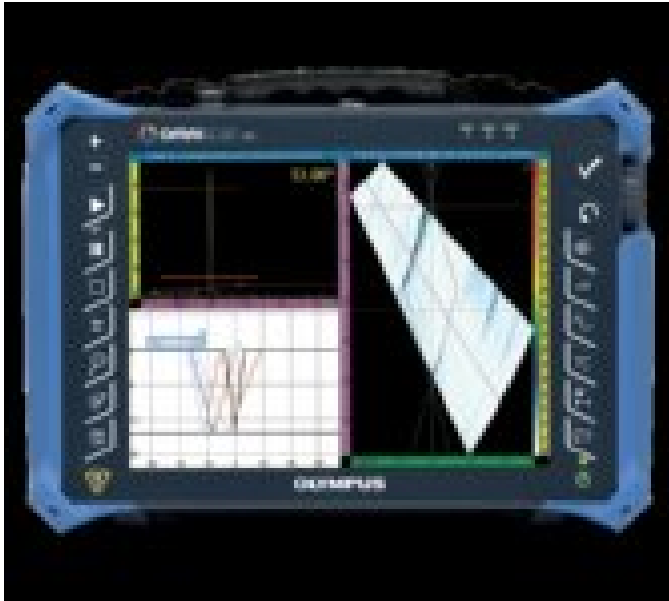wave is generated in the second material. The diagram below shows this effect for a typical angle beam assembly coupled into steel.

3.0 Instrument Overview

3.1 General Description of Flaw Detectors

Modern ultrasonic flaw detectors are small, portable, microprocessor-based instruments suitable for both shop and field use. They generate and display an ultrasonic waveform that is interpreted by a trained operator, often with the aid of analysis software, to locate and categorize flaws in test pieces. They typically include an ultrasonic pulser/receiver, hardware and software for signal capture and analysis, a waveform display, and a data logging module. While some analog-based flaw detectors are still manufactured, most contemporary instruments use digital signal processing for improved stability and precision.

The pulser/receiver provides an excitation pulse to drive the transducer and amplification and filtering for the returning echoes. Pulse amplitude, shape, and damping can be controlled to optimize transducer performance, and receiver gain and bandwidth can be adjusted to optimize signal-to-noise ratios.

Modern flaw detectors typically capture a waveform digitally and then perform various measurement and analysis functions on it. A clock or timer is used to synchronize transducer pulses and provide distance calibration. Signal processing may be as simple as generating a waveform display that shows signal amplitude versus time on a calibrated scale, or as complex as sophisticated digital processing algorithms that incorporate distance/amplitude correction and trigonometric calculations for angled sound paths. Alarm gates are often employed to monitor signal levels at selected points in the wave train to flag echoes from flaws.

The display may be a liquid crystal, an electroluminescent display, or, in older models, a CRT. The screen will typically be calibrated in units of depth or distance. Multicolor displays can be used to provide interpretive assistance.

Internal data loggers can be used to record full waveform and setup information associated with each test, if required for documentation purposes, or selected information like echo amplitude, depth or distance readings, or presence or absence of alarm conditions.

3.2 Block Diagram
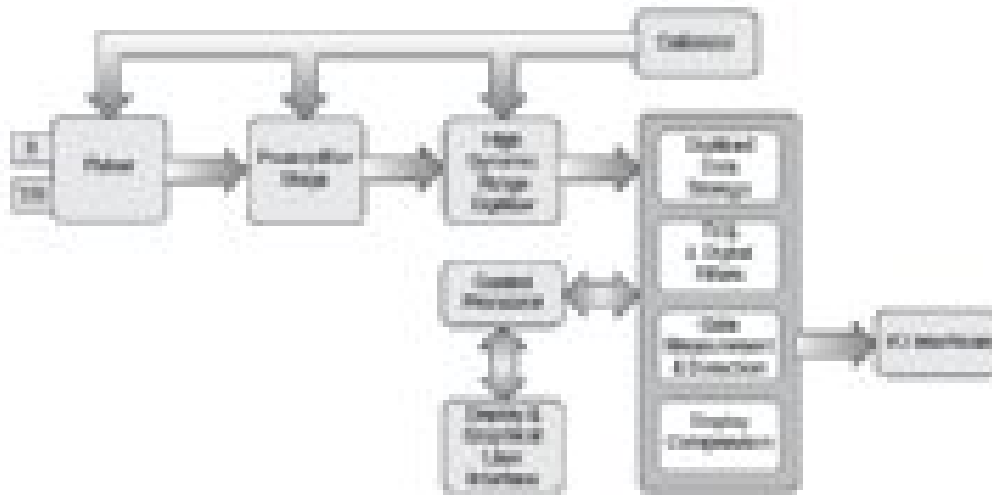
A block diagram of a typical contemporary ultrasonic flaw detector is shown above. In the analog front end, the pulser provides a high voltage impulse to the transducer at a selected pulse repetition frequency, generating the outgoing ultrasonic wave. Echoes returning from the test piece are received by the transducer and converted back into electrical signals, which, in turn, are fed into the receiver. The echoes are amplified as required and then digitized by a high dynamic range digitizer module that is capable of handling the wide variation of signal amplitudes commonly seen in ultrasonic NDT.

The microprocessor-based control and timing logic synchronizes the pulser and the digitizer, selecting the portion of the wave train that will be further processed and displayed. A calibrator is implemented to calibrate DC offset, gain, phase, and frequency response of the analog front end through the digitizer. This calibration scheme ensures drift-free operation, instrument linearity, and unit-to-unit repeatability that are major advantages of digital versus analog signal processing in ultrasonic instruments.

Following digitization, the selected echoes from each data acquisition are stored in the unit's memory. They are further processed by digital bandpass filters to optimize signal-to-noise. Time varied gain (TVG) is applied if it's being employed. The processed echoes are then analyzed through gate and time/amplitude measurement software as programmed by the user, compressed as required for display purposes, and displayed on the instrument's screen.

3.3 Digital Signal Processing

Most modern ultrasonic flaw detectors incorporate digital rather than analog signal processing. While some older analog instruments are still in use, microprocessor-based digital processing is now the industry standard for portable flaw detectors. Its major advantages include:

- Precision and repeatability of test setups, which can be stored for quick recall
- Stability of horizontal and vertical linearity (no drift with time or temperature)

- Digital precision in measurement of amplitude and depth/distance, including trigonometric calculations in angle beam testing
- Digital filtering can improve near-surface resolution and signal-to-noise in high gain applications
- Waveform freeze, peak memory, and zoom functions for easier analysis
- Fast and reliable implementation of sizing techniques such as DAC, TVG, and DGS

- Datalogger software for storage of screen displays and measurements in internal memory or on removable storage cards
- USB interface for offloading test data to computers for storage and further analysis

The potential advantage of analog processing in some cases is faster screen refresh and/or data acquisition rates.

3.4 Pulser and Receiver Operation

All ultrasonic flaw detectors have a number of selectable parameters that are used to optimize the pulser and receiver sections of the instrument setup for a given test.

Typical Pulser Controls
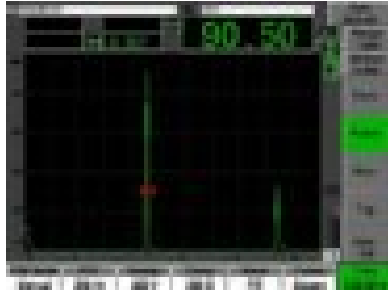
Pulse Type: Two types of excitation pulses are commonly used in portable flaw detectors. A spike pulser generates a broadband pulse with a very fast rise time and an exponential recovery. A square wave pulser generates a single cycle square wave that is tuned to the center frequency of the transducer. Square wave pulsers generally offer greater energy output from a given transducer and are now commonly available.

Pulse width or frequency: As noted above, a square wave pulse must be tuned to the frequency of the transducer. (Spike pulses are broadband and do not need to be tuned.)

Pulse energy or voltage: The amplitude of both spike and square wave pulses may be adjusted for optimum response over typical ranges from 100 V to 400 V or greater. Higher voltage maximizes penetration, while lower voltages improve near-surface resolution and conserve battery life.

Pulse repetition frequency (PRF): This controls the rate at which the pulser fires, typically from 10 Hz to 1000 Hz or greater. A high PRF permits faster scanning and data acquisition, while a low PRF conserves battery life and limits wraparound noise when working with very long sound paths.

Damping: The damping control selects a resistor that modifies the shape of the outgoing waveform.

Standard values are between 50 ohms and 500 ohms. Lower damping resistance increases pulse damping and improves the near-surface resolution, while higher damping resistance reduces damping and improves penetration.

Test Mode: Available modes are pulse-echo, dual, and through-transmission. Pulse-echo mode is the most common setup, using a transducer in which a single element acts as both transmitter and receiver. Dual mode is used with dual element transducers, where a single transducer assembly contains separate transmitter and receiver elements. Through mode is used for setups where two separate transducers are used on opposite sides of the test piece.

Typical Receiver Controls

Gain: All flaw detectors provide adjustable receiver gain over a broad dynamic range (typically 100 dB or more) to account for the wide variation in received signal amplitude among typical tests. Gain adjustment may be divided into base gain and reference gain settings to accommodate certain code requirements. Digital instruments also allow the operator to adjust gain with respect to distance or depth (Time Varied Gain or Distance Amplitude Correction). These functions are discussed in Section 6.

Filtering: Selectable bandpass filtering of the received echoes can often improve the signal-to-noise or near-surface resolution by filtering out unwanted high- or

low-frequency components of the signal. Many instruments provide a broadband setting and choices for narrowband filtering across the total frequency range.

Rectification: Received echoes can be displayed either as an unrectified RF signal, as half wave positive or half wave negative rectified signals, or with full wave rectification. Raw echoes are initially processed as RF waveforms with both positive and negative peaks. The RF display mode is useful when working with very thin test pieces and in cases where echo phase or polarity is of interest. Half wave positive rectification shows only the positive peaks, while half wave negative rectification shows only the negative peaks, flipped to the positive side of the baseline. Half wave rectification can, in some cases, improve signal-to-noise by reducing spurious peaks. Full wave rectification displays both positive and negative echo lobes together on the positive side of the baseline and is the most commonly used format in flaw detection applications.
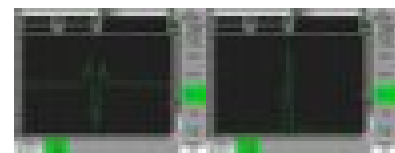
RF mode   Half wave negative
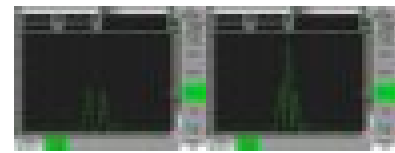
Half wave positive   Full wave

3.5 Display Formats

A-scan display

Any ultrasonic instrument typically records two fundamental parameters of an echo: how large it is (amplitude) and where it occurs in time with respect to a zero point (pulse transit time). Transit time, in turn, is usually correlated to reflector depth or distance, based on the sound velocity of the test material and the simple relationship distance = velocity x time.

The most basic presentation of ultrasonic waveform data is in the form of an A-scan, or waveform display, in which echo amplitude and transit time are plotted on a simple grid with the vertical axis representing amplitude and the horizontal axis representing time. This is the standard format for echo presentation in ultrasonic flaw detection. The example below shows a version with a rectified waveform; unrectified RF displays are also used. The red bar on the screen is a gate that selects a portion of the wave train for analysis, typically measurement of echo amplitude and/or depth.

A-scan Data
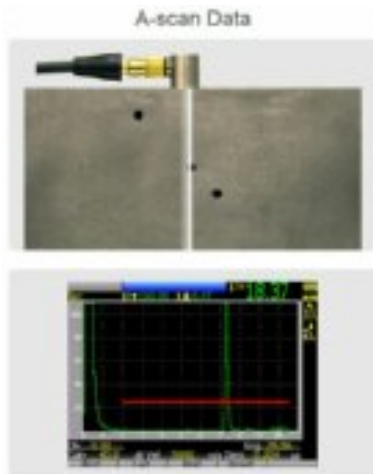
B-scan display

Another way of presenting this information is as a single value B-scan. A B-scan format is commonly used with conventional flaw detectors and corrosion thickness gauges to plot the depth of reflectors with respect to their linear position. The thickness is plotted as a function of time or position while the transducer is scanned along the part to provide its depth profile. Correlating ultrasonic data with actual transducer position enables a proportional view to be plotted and allows the ability to correlate and track data to specific areas of the part being inspected. This position tracking is typically done using electromechanical devices known as encoders. These encoders are used in fixtures that are either manually scanned or in automated systems that move the transducer by a programmable motor-controlled scanner. In either case the encoder records the location of each data acquisition with respect to a desired user-defined scan pattern and index resolution.

In the case below, the B-scan shows two deep reflectors and one shallower reflector, corresponding to the positions of the side-drilled holes in the test block.

B-scan Data
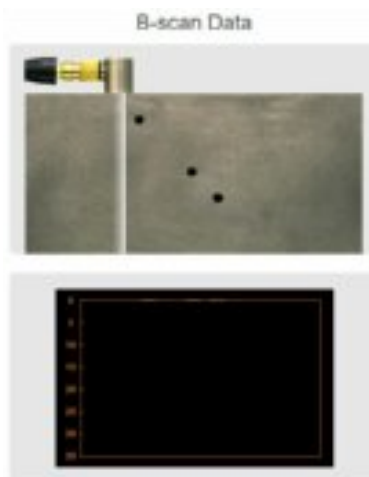
Special A-scan functions

Freeze: A Freeze function is used to freeze a real-time screen display for further analysis, during which the transducer may be removed from the test piece. Many digital flaw detectors permit adjustment of some display, setup, and measurement parameters while the screen is frozen.

Peak Memory: A peak memory function captures and stores the amplitude of each display point on the screen and updates each pixel if a signal of greater amplitude is acquired. The result is a display of the peak amplitude envelope superimposed on the live waveform. Peak memory is useful for capturing flaw indications when scanning a test piece and for capturing the peak response from a reflector during angle beam inspections.

Peak Hold: A Peak Hold function is similar to peak memory except that it represents a one-time screen capture that does not update even if the live waveform exceeds the stored peak. It is typically used to compare a live waveform to that from a reference standard.

Reject: A Reject function eliminates unwanted low-level signals from the A-scan display, which can reduce baseline noise and provide a cleaner picture. However, some test codes prohibit the use of reject since it can also mask small flaw indications. In the example below, a 20% reject level (marked by the horizontal green line) is used to eliminate grain scatter noise in a casting test.

3.6 Calibration Concepts

The term calibration is used for three different processes associated with ultrasonic flaw detectors—velocity/zero calibration, which must be performed whenever a new test material or transducer is being used, reference calibration, which is done to set up a test with respect to a reference standard, and calibration certification, which periodically verifies that the instrument is measuring properly.

Velocity/zero calibration

An ultrasonic flaw detector measures thickness, depth, or distance by very precisely timing echoes. To turn these time measurements into distance measurements, the instrument must be programmed with the speed of sound in the test material as well as any necessary zero offset that is required by the instrument, transducer type, or echo shape. This process is called velocity/zero calibration. The accuracy of any ultrasonic thickness, depth, or distance measurement is only as good as the accuracy and care with which this calibration has been performed. Incorrect calibration will result in inaccurate readings. Fortunately, calibration is usually a simple process, and calibrations for different materials and transducers can be stored and quickly recalled.

In velocity calibration, the flaw detector measures the speed of sound in a reference sample of the test material and then stores that value for use in calculating thickness from measured time intervals. Major factors that affect sound velocity are material density and elasticity, material composition, grain structure, and temperature. In zero calibration, the flaw detector uses a measurement of a material sample of known thickness to calculate a zero offset value that compensates for the portion of the total pulse transit time that represents factors other than the actual sound path in the test piece. The major factor affecting the zero value in common flaw detection applications is wedge delay, or the amount of time it takes for the sound wave to exit the probe. Other factors include electronic switching delays, cable delays, and couplant delays.

The recommended procedure for velocity and zero calibration is a "two-point calibration," which requires samples of the test material of different thicknesses whose dimensions are precisely known. In flaw detection applications, a two-point calibration is frequently performed with an IIW reference block, which provides several sound path lengths. The transducer is coupled to long and short sound paths of known length, the instrument measures pulse transit time at each, and the operator enters the known thickness or distance. Using those four available data points, the two entered thickness or distance values plus the measured transit time associated with each, the instrument calculates the unique velocity and zero values that solve that equation. Those values will then be used for measurements and can be stored as part of a setup.

Most contemporary digital flaw detectors have software prompts designed to guide the user through the initial velocity/zero calibration process. This process will be described in further detail in Section 4.

Reference calibration

Reference calibration is the process of setting up a specific test with respect to appropriate test blocks or similar reference standards. Typically, this involves establishing a signal amplitude level from a reference standard for comparison to indications from the test piece. The details of required reference calibrations are normally found in the procedures established by the user for each specific test.

Calibration certification

Calibration certification is the process of documenting the measurement accuracy and linearity of an ultrasonic instrument under specific test conditions. In the case of flaw detectors, both horizontal (depth or distance) and vertical (amplitude) certifications are provided. Frequently, this certification is performed in accordance with a recognized standard or code, such as ASTM E-317 or EN12668. Measurement accuracy under documented test conditions is typically compared with the manufacturer's established tolerance for a given instrument. In the case of older analog instruments, calibration certification must be done manually with an operator collecting data, but digital instruments are often certified in an automated process using computer software that verifies relevant parameters.

Because measurement accuracy in flaw detection applications is highly dependent on proper setup as well as the integrity of the instrument itself, it is the responsibility of the user to verify measurement accuracy to whatever level he/she requires for a given test. This is usually easy to do by simply checking readings with appropriate reference standards.

3.7 Typical Specifications

When evaluating conventional flaw detectors, a number of functional characteristics are often specified. These characteristics are generally shared with phased array instruments. Not all the items listed below are available in all instruments.

Pulser and Receiver:

Largely defines the operating range of transducers that can be used with the instrument.

PULSER

Available Spike Pulser
Available Square Wave Pulser
Pulser Repetition Frequency

RECEIVER

Overall Bandwidth
Available Narrowband Filters
Time Varied Gain
Overall Dynamic Range

Measurement and Display:

Parameters defining the general measurement and display modes of an instrument: Number of alarm/measurement gates

- A-scan display modes: Rectification (RF, Full Wave, Half Wave), Maximum, Composite, Averaged, Hollow, Filled, and Peak Memory
- Range
- Measurement resolution
- Measurement types (i.e., sound path, depth, distance from front of probe, dB, dB to curve, etc.)
- Single value B-scan mode (not available on most flaw detectors)
- Screen refresh rate
- Available sizing software

Physical/Operational:

- Size and weight
- Form factor, including control layout
- Compliance with industry standards for shock, vibration, drop, moisture, RF/EMI interference, etc.
- Battery life

4.0 Basic Setup Techniques

4.1 General Concepts of Transducer Selection

Transducer Selection

In many cases, the type of transducer used in a particular test will be determined by established inspection code or procedural requirements that the inspector needs to follow. Codes such as AWS D1.1 and ASTM E-164 detail recommended transducers and wedges, and, in some cases, transducer selection will be governed by past practices in the same test. If there is no code or procedure in place, then the inspector must select an appropriate transducer based on the specific test requirements and using his or her knowledge of common test practices and general ultrasonic theory. In some cases, this will involve experimentation with several types of transducers on reference standards representing the part to be tested to determine which one provides the best response.

The transducers used in ultrasonic flaw detection generally fall into five categories:
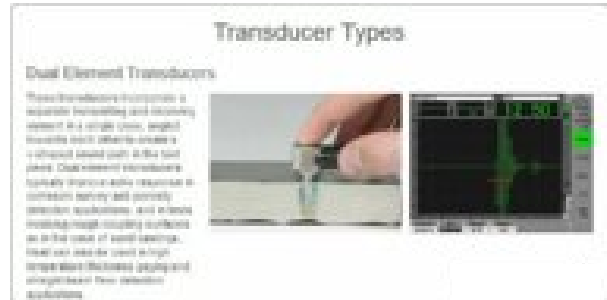
Once a transducer type has been selected, other important factors affecting performance are frequency, diameter, and bandwidth. These were reviewed in . Optimizing these factors in a given test often requires balancing advantages and disadvantages.

Frequency: Higher frequency transducers can resolve smaller flaws due to their shorter wavelength, while lower frequency transducers will penetrate farther in a given material because attenuation decreases with frequency.

Diameter: Larger-diameter transducers can scan a given area more quickly, while smaller diameters will have better response to small reflectors and couple more efficiently into curved surfaces.

Bandwidth: Narrowband transducers have greater penetration but reduced near-surface resolution, while broadband transducers have better near-surface resolution but less penetration.

4.2 Typical Straight Beam Contact Setup Procedure

Straight Beam Contact Setup

STEP 1 2 3 4 5

STEP 1

Set the zero-offset to zero and set velocity to the approximate velocity of the test material.

If the velocity is unknown, you can start with a generic value of approximately 5,000 m/s(μ) or 2000 in(μ) for most metals, or 2,100 m/s(μ) or 1000 in(μ) for most engineering plastics and composites.

Set the range to a value large enough to cover the thickest calibration sample.

Straight Beam Contact Setup

STEP 1 2 3 4 5

STEP 2

Couple the transducer to the calibration samples and observe the echoes.

Adjust the instrument's pulser and receiver settings as required to obtain clean echoes.

Settings typically include pulse frequency, energy, damping, receiver filtering, and gain.

Straight Beam Contact Setup

STEP 1 2 3 4 5

STEP 3

- Couple the transducer to a thin sample.
- Place a measurement gate on the echo and set echo height to approximately 80%.
- Initiate a zero calibration as described in the instrument operating manual. Enter the known thickness of the thin sample.

Place measurement gate and set echo height   Enter thickness of test sample

Straight Beam Contact Setup

STEP 1 2 3 4 5

STEP 4

- Couple the transducer to a thick sample.
- Move the measurement gate to final echo and set echo height to approximately 80%. Initiate a velocity calibration as described in the instrument operating manual.
- Enter the known thickness of the thick sample.

Move measurement gate and set echo height   Enter thickness of thick sample

Straight Beam Contact Setup

STEP 1 2 3 4 5

STEP 5

Recheck the thick and thin samples, and verify that thickness measurements are accurate.

Thick sample measurement   Thin sample measurement

4.3 Typical Angle Beam Setup Procedure

Angle beam calibration requires the use of an appropriate test block that provides two sound paths of known length. Commonly, this will be an ASTM E-164 or IIW-type block, although other standards, like AWS DSC blocks, can also be used. The general procedure description below assumes use of an IIW Type 1 calibration block or equivalent.

As with any other transducer calibration, this should be performed using a block made of the same material as the test piece. Angle beam calibration blocks are commercially available in a variety of steel alloys as well as aluminum and titanium.

Angle Beam Setup Procedure

Introduction | STEP [1] [2] [3] | Index

Verifying the Refracted Angle - Introduction

All commercially offered wedges are marked with a nominal angle, which is normally verified by the manufacturer to be within +/- 2 degrees or better based on typical shear wave velocities.
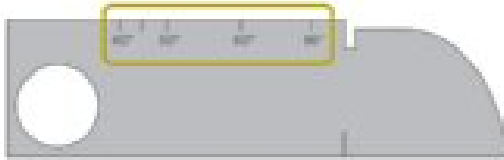
Aside from the manufacturing tolerance, this angle can vary with wedge wear, and because it is based on wave refraction it will vary whenever the shear wave velocity in the test material changes.

Many test procedures call for verifying the wedge angle as part of initial calibration.

Angle Beam Setup Procedure

Introduction | STEP [1] [2] [3] | Index

Refracted Angle - Step 1

For 45 degree and 60 degree wedges, couple the wedge to the block as shown below and identify the echo from the large hole.

For 70 degree wedges, turn the block over and couple to the opposite side, again aiming at the hole.
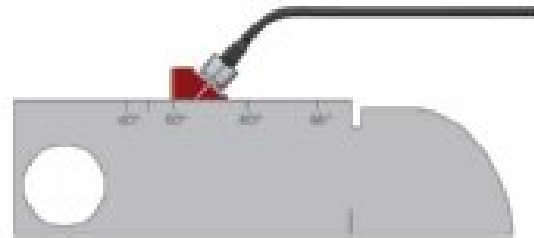
Angle Beam Setup Procedure

Introduction | STEP [1] [2] [3] | Index

Refracted Angle - Step 2

Move the wedge forward and backward and locate the point at which the echo peaks. The peak memory function available in most instruments can be used to draw the echo envelope for confirmation.

3.479
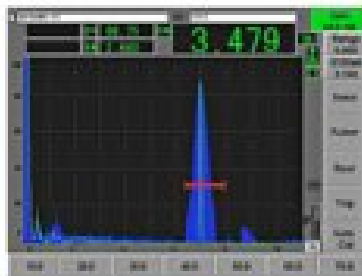
Angle Beam Setup Procedure

Introduction | STEP [1] [2] [3] | Index

Refracted Angle - Step 3

With the echo peaked up, note the degree mark on the test block that lines up with the BIP established in the first procedure. This is the actual refracted angle for that wedge assembly in metal whose shear wave velocity matches that of the test block. It may differ slightly from the angle marked on the wedge. Enter this measured angle in the instrument as the angle value to be used for depth and distance calculation.

Angle Beam Setup Procedure

Introduction | STEP [1] [2] [3] [4] | Index

Velocity and Zero Calibration (Distance Calibration) - Introduction

In angle beam setups it is necessary to establish a zero offset that compensates for the portion of the sound path that falls inside the wedge, and also calibrate for material sound velocity as in any other flaw detector setup.

This is commonly done as a two-step calibration using two reflectors in an IIW-type block or a similar reference standard that provides two reflections at known distances.

IIW TYPE 1 REFERENCE BLOCK

Angle Beam Setup Procedure

Introduction | STEP [1] [2] [3] [4] | Index

Distance Calibration - Step 1

Set the instrument range to 10" or 250 mm. Couple the wedge to the test block as shown below, so that the beam index point is directly over the zero mark. Identify the echo from the 100 mm or 4" radius and peak it up.
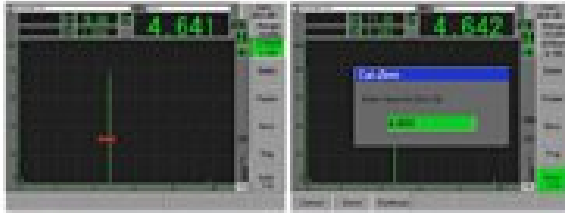
4"   1"

IIW TYPE 1 REFERENCE BLOCK

Angle Beam Setup Procedure

Distance Calibration - Step 2

Place a measurement gate on the radius echo and set the echo height to approximately 80%. Initiate a zero-calibration as described in the instrument operating manual. Enter the known soundpath length of 100 mm or 4.000 inches.

Angle Beam Setup Procedure

Distance Calibration - Step 4

Conclude the calibration process as described in the instrument manual.

Recheck the two echoes and verify that distance measurements are accurate.

Angle Beam Setup Procedure

Distance Calibration - Step 3

Identify the echo representing the 225 mm or 9 round path from the small radius reflector located behind the wedge and peak it up. It may be necessary to increase gain in order to see it since it will be much smaller than the first echo, and it may be preceded by a still smaller echo representing a multiple of the 100mm 4" path. Move the measurement gate to that echo and set the echo height to a level such that it can be clearly seen. Initiate a velocity calibration as described in the instrument operating manual. Enter the known soundpath length of 225 mm or 9.000 inches.

31
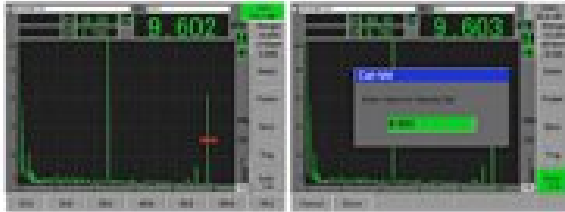
4.4 Typical Dual Element Setup Procedure

Dual element transducers incorporate separate transmitting and receiving elements and are commonly used in corrosion survey applications, for porosity detection in castings, and in tests involving rough surfaces or high temperatures. The general procedure for dual element transducer calibration is basically the same as that for contact transducers, the two-step calibration found in section 4.2, with the following additional notes.

1. Remember to set the flaw detector's pulser to "dual" mode when working with dual element transducers.
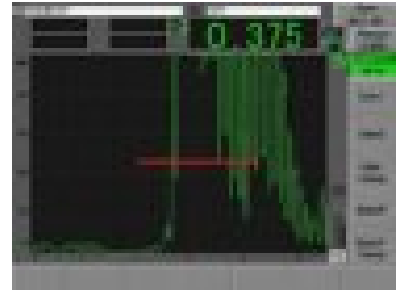
2. When using dual element transducers for thickness measurement, the gain is generally set very high so that the leading edge of the back wall echoes appear as nearly vertical lines on the screen. This is because of the multi-cycle echoes that duals produce. Gates should be set to read to the leading edge rather than the echo peak.

Peak measurement, may be unreliable.

Leading edge measurement, recommended.

3. Because of duals' characteristic V-shaped sound path and the lack of V-path correction software in many flaw detectors, there is some non-linearity in thickness measurements of thin materials. The degree to which this occurs in a setup can be determined by checking reference blocks of various thicknesses.

4. The zero-offset value for dual element transducers will increase as the transducer heats up. If the temperature of the test piece is significantly hotter than the calibration temperature, the zero calibration should be redone at the higher working temperature.

4.5 Typical Delay Line and Immersion Transducer Setup Procedure

Delay line and immersion transducers use either a plastic or epoxy delay line or a water path between the transducer's active element and the test piece. The echo from the end of the delay line, or from the front surface of the test piece in immersion setups, is used as the zero reference for depth or distance measurements. (This echo is often referred to as the interface echo.) Otherwise, the calibration procedure is similar to that for single element contact transducers, using two reference samples of known thickness.

Delay Line and Immersion Transducer Setup

STEP 1 2 3 4 5 6

STEP 1

Set the zero-offset to zero and set velocity to the approximate velocity of the test material.

If the velocity is unknown, you can start with a generic value of approximately 5,900 mm/uS or 2330 m/uS for steel and similar metals, or 2,500 mm/us or 1090 m/uS for most engineering plastics and composites.

Set the range to a value large enough to cover the thickest calibration sample plus the acoustic length of the delay line or water path. If testing metal, the acoustic length of a typical delay line of steel velocity will be approximately twice its mechanical length, and the acoustic length of a water path will be approximately four times its mechanical length.

Delay Line and Immersion Transducer Setup

STEP 1 2 3 4 5 6

STEP 2

Identify the delay line or water path echoes. The excitation pulse should be at the left edge of the screen and delay line or water path echoes will follow.

Delay line echoes can be verified by touching the tip with a wet fingertip; echo amplitude will be reduced. Front surface echoes in immersion tests can be verified by blocking the sound beam with a fingertip; the echo will disappear.

When you have identified the first delay line or water path echo, adjust the zero offset to move it to the left edge of the screen, as seen in the second image below.

1.190   0.032

Delay Line and Immersion Transducer Setup

STEP 1 2 3 4 5 6

STEP 3

Couple the transducer to the calibration samples and observe the echoes.

Adjust the instrument's pulser and receiver settings as required to obtain clean echoes. Settings typically include pulse frequency, energy, damping, receiver filtering, and gain.

When testing thin materials with delay line transducers, it is usually advantageous to work with rectified RF signals for clearer peak resolution.

0.028

Delay Line and Immersion Transducer Setup

STEP 1 2 3 4 5 6

STEP 4

Couple the transducer to a thin sample.

Place a measurement gate on the echo and set echo height to approximately 80%. Initiate a zero calibration as described in the instrument operating manual.

Enter the known thickness of the thin sample.

0.135   0.136

Delay Line and Immersion Transducer Setup

STEP 1 2 3 4 5 6

STEP 5

Couple the transducer to a thick sample that is within its measurement range.

Move the measurement gate to that echo and set echo height to approximately 80%. Initiate a velocity calibration as described in the instrument operating manual.

Enter the known thickness of the thick sample.

0.435   0.436

Delay Line and Immersion Transducer Setup

STEP 1 2 3 4 5 6

STEP 6

Conclude the calibration process as described in the instrument manual.

Recheck the thick and thin samples and verify that thickness measurements are accurate.

0.100   0.400

5.0 Basic Approaches for Inspection

5.1 Straight Beam Tests (Plates, Bars, Forgings, Castings, etc.)

Straight beam testing is generally employed to find cracks or delaminations parallel to the surface of a test piece, as well as voids and porosity. It may use contact, delay line, dual element, or immersion transducers, all of which launch longitudinal waves on a straight path into the test piece. Common applications include testing plates, bars, forgings, and castings, as well as bolts and hanger pins and similar parts that can crack parallel to an accessible surface. Straight beam testing is also commonly employed in testing fiberglass and composites, as discussed in <u>section 7.6</u>.

Like all other ultrasonic flaw detection techniques, straight beam testing utilizes the basic principle that sound energy traveling through a medium will continue to propagate until it either disperses or reflects off a boundary with another material, such as the air surrounding a far wall or the gap created by a crack or similar discontinuity. In this type of test, the operator couples the transducer to the test piece and identifies the echo returning from the far wall, as well as any fixed reflections originating from geometrical structures such as grooves or flanges. After noting the characteristic pattern

of echoes derived from a good part, the operator then looks for any additional echoes that appear ahead of that back wall echo in a test piece, discounting grain scatter noise, if present. An acoustically significant echo that precedes the back wall echo implies the presence of a laminar crack or void. Through further analysis, the depth, size, and shape of the structure producing the reflection can be determined.

No Flaw Present

Sound travels through the material and reflects off the back wall.
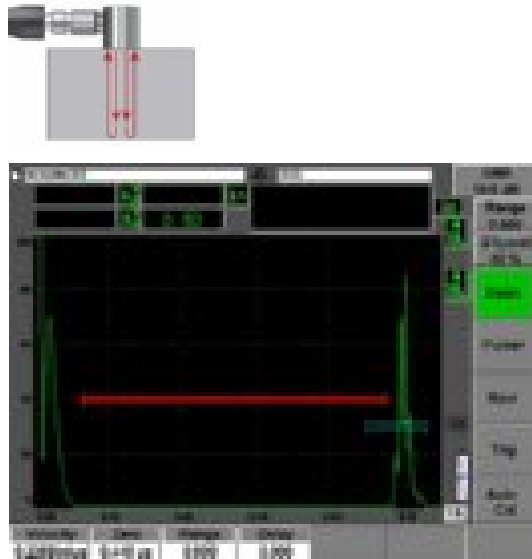
Flaw Present

- Some sound travels through the entire material and reflects off the back wall, while some reflects off the intermediary flaw
- The echo amplitude correlates to flaw size
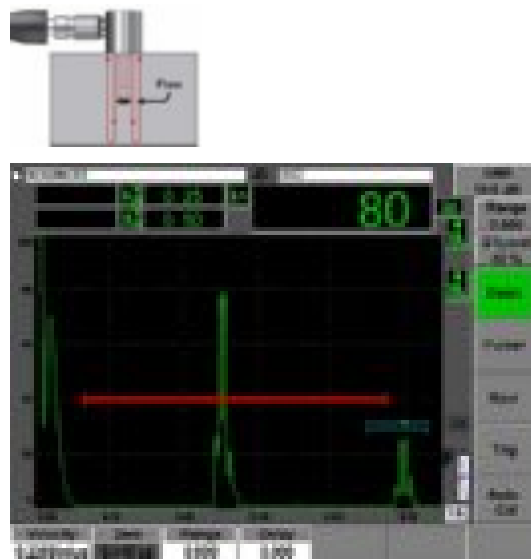
In the case of flat plates and smooth bars, this procedure is usually straightforward.

Straight beam testing can also be used to test braze joints and other bond lines that are oriented parallel to the surface. In these cases, even a good joint typically returns an echo since the braze metal or bonding material differs from the material

being joined. However, comparative testing will normally show that a lack of bonding returns an even larger echo, so the bond line echo amplitude is used as an indicator of the bond condition.

Straight beam testing can also be used to test braze joints and other bond lines that are oriented parallel to the surface. In these cases, even

a good joint typically returns an echo since the braze metal or bonding material differs from the material being joined. However, comparative testing will normally show that a lack of bonding returns an even larger echo, so the bond line echo amplitude is used as an indicator of the bond condition.

5.2 Angle Beam Inspection

While straight beam techniques can be highly effective at finding laminar flaws, they are not effective when testing many common welds where discontinuities are typically not oriented parallel to the surface of the part. The combination of weld geometry, the orientation of flaws, and the presence of the weld crown or bead require inspection from the side of the weld using a beam generated at an angle. Angle beam testing is by far the most commonly used technique in ultrasonic flaw detection.

Angle beam probes consist of a transducer and a wedge, which may be separate parts or built into a single housing. They use the principle of refraction and mode conversion at a boundary to produce refracted shear or longitudinal waves in a test piece.
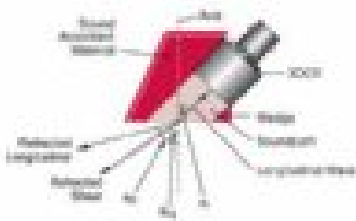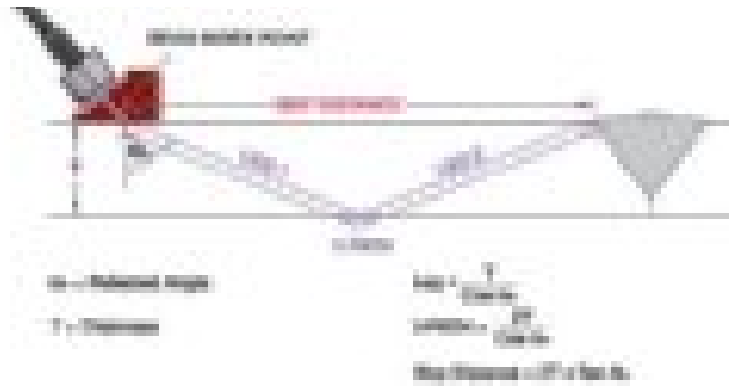

Most commonly used angle beam probes generate a refracted shear wave at standardized angles of 45, 60, or 70 degrees in the test material. The incident angle necessary to produce a desired refracted angle is based on material sound velocities and is calculated from Snell's law using the equation below.

In the typical case of a plastic or epoxy wedge coupled to steel, low incident angles will generate both longitudinal and shear wave beam components, and specialized longitudinal wave angle beam

In typical inspections the sound beam will travel at the generated angle down to the bottom of the test piece and then reflect upward at the same angle. Moving the probe back and forth causes the sound beam to sweep across the full height of a weld. This scanning motion enables inspection of the entire weld volume and detection of discontinuities both at the fusion lines and within the weld body.

wedges do exist. However, at commonly used inspection angles only a primary shear wave will be generated since the L-wave solution to the equation would exceed 90 degrees, which is not possible.

As in the case of straight beam testing, in angle beam testing the operator looks for reflections corresponding to discontinuities. During initial setup the operator must note any echoes that originate from the weld bead or other geometric structures. Additional echoes appearing within the zone representing the weld would correspond to a lack of fusion, cracking, porosity, or other discontinuities whose type, depth, and size can be determined through further analysis.
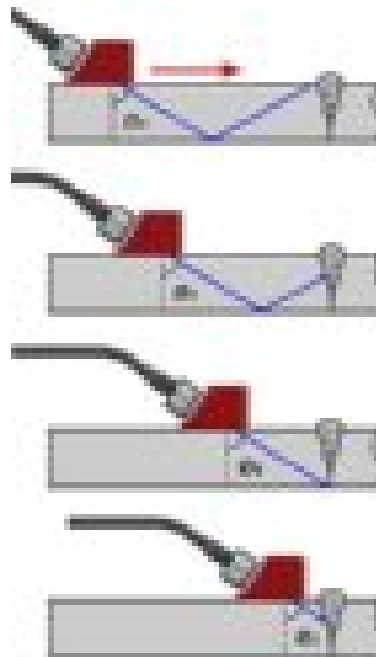
In the example below, the sound beam passes through a good weld without reflecting back, and no significant indications are seen on the screen. A discontinuity within the weld zone, however, causes a strong reflection with the zone of interest, marked by the red gate.
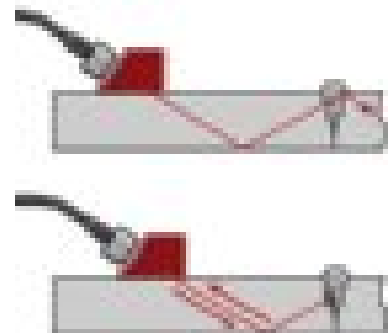
6.0 Basic Construction Weld Inspection Concepts

6.1 Welding Overview

Welding is the common process of joining materials through melting and fusion, and inspecting structural welds in metals is a very common application for ultrasonic flaw detection. Welding can be done using several methods, including electric arcs, gas flames, and lasers, but for ultrasonic testing, the geometry of a weld rather than how it was made is the primary concern. This section focuses on common construction welds typically used to join pipes, plates, and metal structures.

Welding overview

There are a potentially large number of possible weld geometries, but those commonly inspected by ultrasonic techniques fall into four basic categories.
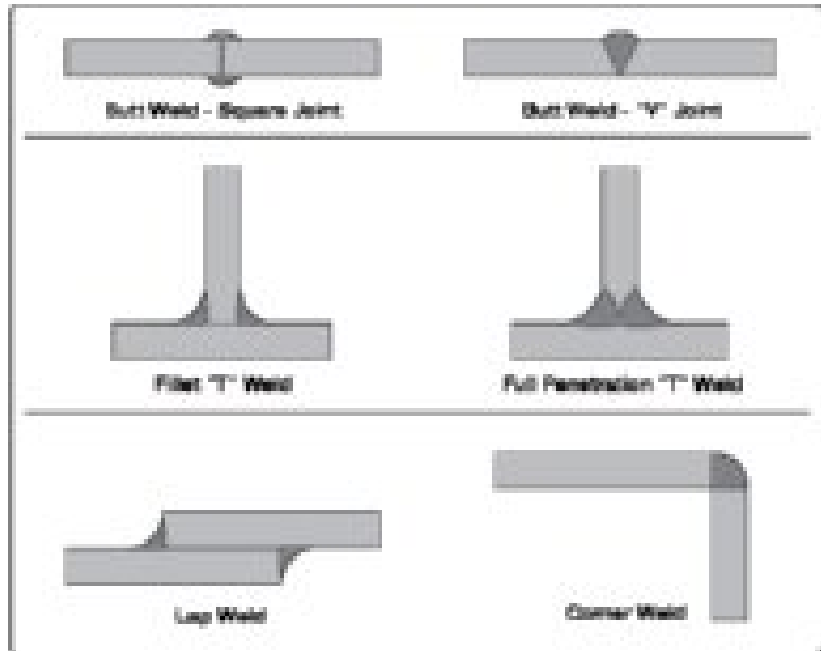
The most commonly encountered flaw types are cracking, lack of fusion, incomplete penetration, porosity, and slag inclusions. All of these are potentially detectable through ultrasonic testing.
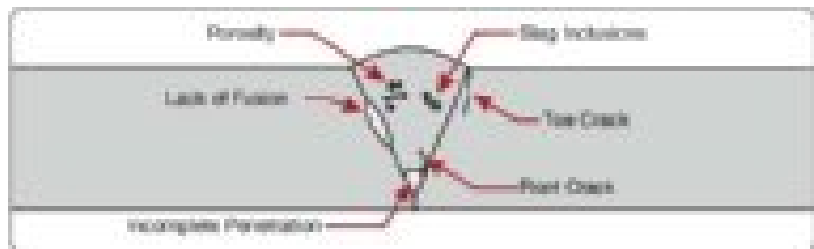
6.2 Angle Beam Probe Selection

The various types of ultrasonic transducers used in flaw detection applications were discussed in Section 4.1. In construction weld inspection, angle beam probes are the primary tool, supplemented by straight beam transducers. Angle beam probes may be comprised of separate, interchangeable transducers and wedges, or they may be integral assemblies. In many cases, the transducer/wedge combination to be used for an inspection will be specified by a relevant code or inspection procedure. If no probe has been specified, the inspector must select one appropriate for the test based on the following considerations.
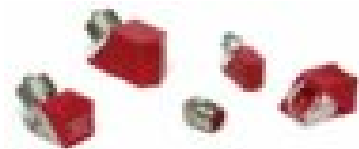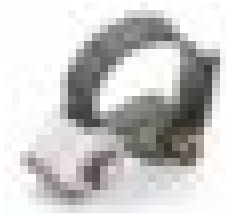
Frequency

Angle beam transducers are generally available in frequencies from 500 KHz to 10 MHz, however, most weld testing is performed at frequencies between 2 MHz and 5 MHz. Lower frequencies provide greater penetration across long sound paths or through coarse-grained metal, while higher frequencies provide better resolution of small flaws. If not otherwise specified by code, 4 MHz or 5 MHz is usually a good frequency with which to begin an evaluation.

Angle

Almost all angle beam testing is performed at standard angles of 45, 60, and 70 degrees, although 30-degree and 90-degree (surface wave) wedges are also used in some cases. As a general rule, higher angle (60- and 70-degree) wedges are used when the metal's thickness is less than 25 mm (1 in.), and lower angle (45-degree) wedges are commonly used when metal's thickness is greater than 50 mm (2 in.). Two or three different angles may be used in a given test based on the part's geometry and flaw resolution requirements. Further information can be found in common inspection codes. The wedge angle in a given case should be high enough that a first leg signal can reach the weld root from a position on the part surface that is not obstructed by the weld crown.

Size

Angle beam transducers and wedges are available in a wide range of shapes and sizes, with round, square, or rectangular elements. North American industry practice favors the use of round elements (except in AWS code inspections), while European practice favors square or rectangular. The most common element sizes include 0.25 in., 0.5 in., and 1 in. diameter for round elements and 8 × 9 mm, 14 × 14 mm, and 20 × 22 mm for square/rectangular elements. However, a number of other standard sizes are also available. Smaller elements can provide better resolution of small flaws, and smaller wedges can more easily conform to curved surfaces. Larger elements provide more area coverage and faster scanning, as well as reduced beam spreading across long sound paths.

With these considerations in mind, the inspector should use his/her knowledge and experience to select the optimum probe or probes for a test. Where possible, probe performance should be verified on test standards containing appropriate reference reflectors or known defects.

6.3 Probe Positions with Respect to Weld Geometry

Weld inspection procedures usually require testing from two or more different locations on the test piece to cover the entire volume of the weld and to project sound waves in the directions required for generating reflections from common flaws. In all cases the probe must be scanned back and forth to project the sound beam through the entire volume of the weld. Specific procedures for a given test must always be established by the inspector, based on part geometry and test requirements.

6.4 Common Test Practices

Scan patterns

In any ultrasonic test, the operator must move the transducer to cover the entire material volume that must be inspected and to cover the range of orientations needed to detect all likely flaws. While scan patterns should always be established with respect to specific test requirements, a common pattern is like this:
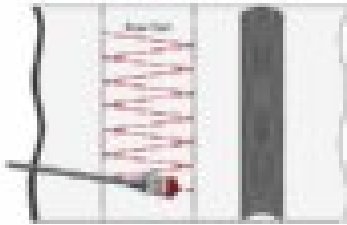
The probe is scanned back and forth between the surface point corresponding to a second leg test of the upper part of the weld (left limit in drawing) and the point corresponding to a first leg test of the lower part of the weld (right limit). The wedge is angled slightly in alternate directions, and at each pass it is indexed by approximately one-half its width. This pattern provides full top-to-bottom coverage of the weld while helping ensure that there are no coverage gaps in the lateral direction. The angulation helps detect inclusions, porosity, and other irregularly shaped reflectors. The test is then repeated from the other side of the weld.

When an indication is observed during this test, procedures may call for further scanning with probe rotation around the reflector and across an outside arc while aimed at the reflector. These motions help identify the type of reflector, as discussed in Section 6.6.
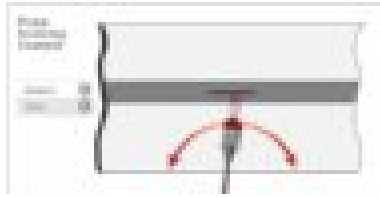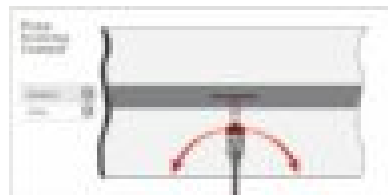
Some procedures also call for a scan along the length of the weld axis, with the wedge aimed slightly inward. The purpose of this scan is to identify transverse cracking in the weld zone, which may not be visible when the beam is perpendicular to the weld. Again, the test is performed from both sides.

A final test is a straight beam examination of the heat affected zone (HAZ) on both sides of the weld to identify possible laminar cracks. This test typically uses a small-diameter contact transducer to identify indications coming ahead of the back wall echo.
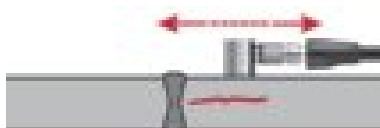
Positioning with respect to crown

As noted above, angle beam tests from the side of a weld typically require scanning the probe back and forth between the points where the beam hits the bottom of the weld (first leg) and the top of the weld (second leg). The corresponding points on each side of the weld can be marked with lines on the surface of the parts. Guides or templates can be fabricated to help maintain positioning, especially when performing a single-pass scan of the weld root or crown.

In some cases involving large wedges, relatively thin metal, and large crowns, it may not be possible

to position the wedge close enough to the weld to optimize the first leg reflection from the weld root. In such cases, a smaller wedge or a wedge designed with a short approach distance should be used. Alternately, testing can be performed in the second and third legs rather than first and second, but that may be less desirable due to attenuation and beam spreading effects.

Contouring

Angle beam inspection of circumferential and axial welds in small-diameter pipes and tubes can require contoured wedges for proper coupling. Contouring is generally recommended whenever the diameter becomes small enough that it is difficult to hold the wedge normal to the test piece and/or when the curvature significantly limits the area of the wedge in contact with the test piece on a convex radius or creates a visible gap under the wedge on a concave radius. Typical wedge contours are shown below.

AID (Axial Inside Diameter)

AOD (Axial Outside Diameter)

CID (Circumferential Inside Diameter)

COD (Circumferential Outside Diameter)

6.5 Typical Screen Display Information

Modern flaw detectors provide a variety of measurement readouts as an aid to identifying and documenting the location of reflectors. These include the amplitude of gate echoes, sound path length and depth/distance measurements, and leg indicators. With proper calibration, depth/distance measurements can be accurate to +/- 0.1 mm (0.004 in.). Horizontal displays can be scaled with respect to sound path length or leg/skip distances.

6.6 Basic Waveform Interpretation

Interpreting ultrasonic waveforms always requires proper training and experience. A trained operator can use echo characteristics to determine the geometry of a flaw as well as its location. This section provides a simplified overview of some commonly encountered indications. Note that these examples are intended for concept demonstration only and are not intended as a substitute for interpretation by a trained operator who is aware of the requirements of the specific test.

In all cases, an initial angle beam calibration should first be performed as discussed in section 4.3. Most test procedures will also specify how to set a reference gain level, using the side-drilled hole in an IIW block or a similar reference reflector to normalize the starting gain level for an inspection. Once this has been done, testing can begin, commonly using the probe movement pattern described in section 6.4.

Peaking up

When an indication is observed during scanning, the next step is normally to identify the probe position that produces the maximum reflected amplitude. This procedure is known as "peaking up," and it is performed in two directions, first along the length of the weld (transverse direction) and then with respect to distance from the weld (axial direction). Peak memory software that draws an echo envelope is very helpful here for documenting the probe location that produces the largest signal.

Transverse peak up

Axial peak up

The transverse peak-up procedure can also be used to determine the transverse width of the flaw. A common procedure is the 6 dB drop technique, demonstrated in the graphic to the right, in which the probe is moved from left to right while noting the two points where the maximum reflection that is seen at the middle of the flaw drops to 50% at the edges. The distance between the probe center at each of those two points represents the width of the flaw. Other procedures may use a different amplitude point as the reference.
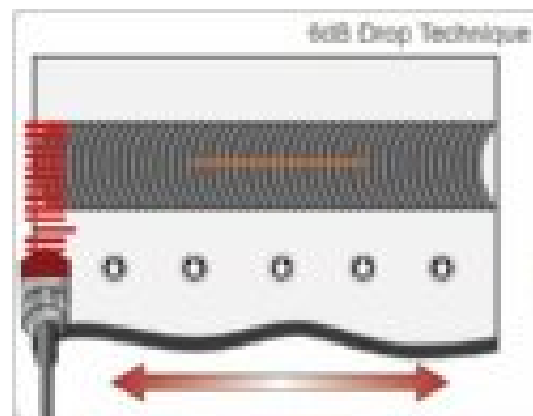
Examples of flaw indications

(a) Incomplete penetration — This typically generates a very strong reflection from the base of the weld at the first leg /second leg boundary. The same indication is observed if the weld is scanned from the other side.

(b) Lack of fusion — This typically generates a strong reflection with fast rise and fall time in the second leg from one side of the weld and a weaker third leg indication or nothing from the other side. Prolonged response with axial scanning indicates the cross-sectional length. The first image below shows the signal when the weld is scanned from the side with the fusion gap, and the second image shows the same reflector as seen from the other side.

(c) Root crack — This typically generates a first leg signal from bottom of the weld, with the crack indication appearing close to a reflection from the bottom weld bead. The first video below shows the signal when the weld is scanned from the side of the root crack, with the crack indication in the gate and the weld bead echo following it the L1 graticule. The second image shows the same reflector as seen from the other side, with a strong bead echo preceding the crack indication.
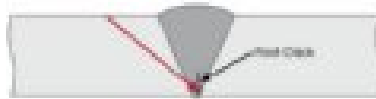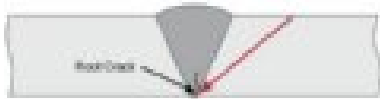
(d) Toe crack — This typically produces a second leg signal from the top of the weld, ahead of the crown echo when tested from one side and following the crown echo when tested from the other. In the images below, the crown echo is located at the L2 graticule. The first image below shows the signal when the weld is scanned from the side with the toe crack, and the second image shows the same reflector as seen from the other side. As non-planar defects, cracks can often produce multifaceted reflections.
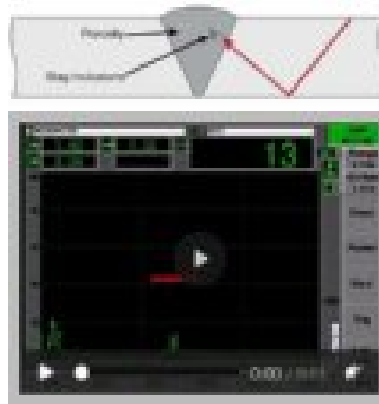
(e) Porosity and slag inclusions — These typically produce a cluster of echoes that exhibit multiple facets as the probe is rotated. Indications will often not be as strong as those seen from planar defects and large cracks. Slag can look very similar to porosity. The multi-faceted echo may not be as strong as from porosity, and peak shapes and amplitudes will change rapidly with probe rotation.

6.7 Inspection Codes

As is the case in many established industries, the ultrasonic NDT community has developed a number of codes, standards, and recommended practices that are intended to help standardize test and inspection procedures as well as the interpretation and reporting of results. Many of these are issued by professional organizations such as the American Welding Society (AWS) or American Society for Nondestructive Testing (ASNT), or national/regional standards bodies like the European Committee for Standardization (CEN). Others come from private industry, like the aircraft service bulletins that are prepared and distributed by aerospace manufacturers. These documents provide guidance for inspectors and a common frame of reference for communication between the parties involved in a process, such as a manufacturer and customer or inspection contractor and employer.

While codes vary in their scope and level of detail, many cover the following topics:

- Qualification of inspection personnel
- Type of equipment and probes to be used
- Method of set up and calibration
- Inspection procedure
- Interpretation of results
- Documentation and reporting

There are hundreds of established ultrasonic test and inspection codes in use worldwide. Copies of these documents may be obtained from the issuing organizations.

7.0 Other Common Applications

7.1 Primary Metals

Primary metal products such as ingots, bars, plates, and tubes are the raw material from which numerous products are made. Since flaws in the material will result in flaws in the finished products, these primary products are commonly inspected at their origin.

Ingots — Discontinuities such as shrinkage cavities (piping) and nonmetallic inclusions in ingots can often be identified though simple straight beam tests looking for localized echoes that appear ahead of the back wall. Both contact transducers and immersion scanning systems can be employed. The minimum flaw resolution in a given test is primarily governed by ingot thickness and grain structure.

Plates — Testing plates is similar to that of ingots in that straight beam contact transducers or immersion scanning are commonly used. Laminar cracking can be identified through straight beam testing. If cracking perpendicular to the surface is suspected, angle beam testing can also be performed.

Bars and Tubes — Solid bars are commonly tested with a straight beam longitudinal wave transducer in either contact or immersion mode, looking for laminar cracking, piping voids, and inclusions. Contact testing is also performed from the ends to check for cracks parallel to the ends.

As mentioned above, multichannel immersion systems are available for automated testing. By using several probes at once and moving the product past the probes or the probes across the part, inspection speed and defect detection can be increased. For example, tubes and pipes are commonly tested for cracking with shear waves generated by either angle beam or immersion transducers and aimed both axially and circumferentially. Plate inspection often raster scans a paintbrush probe across the part, helping ensure 100% inspection.

7.2 Shafts, Forgings, and Bolts

Shafts and bolts have in common a long cylindrical geometry that is usually suitable for ultrasonic testing. Since cracks tend to occur perpendicular to the ends, testing is typically performed with straight beam transducers (from both ends in the case of long shafts). In both cases, the typical procedure is to identify the echo from the far end and look for echoes appearing ahead of that peak as the transducer is moved around the face of the part.

In the case of bolt inspection, the operator must note any thread echoes that are generated by the part and look for crack indications that appear against that background. Note that the surface of the bolt must be sufficiently flat to permit proper sound coupling, thus bolts with rounded or hex-type heads may not be inspectable. Bridge hanger pins represent a related application, and they can usually be tested for shearing with a similar straight beam test. The example below shows detection of a small notch representing a crack originating in the threads of a 212 mm (8.35 in.) bolt, using a 10 MHz contact transducer. The waveform shows the back wall echo from an intact bolt, and the waveform shows the indication from the reference notch in the "cracked" sample.
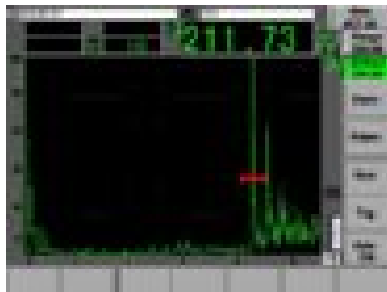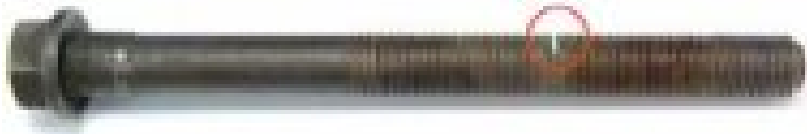
Good bolt, gate on back wall echo

Indication from reference notch

While inspecting smooth shafts, even very long ones, is usually straightforward, shafts whose diameter changes in steps require special consideration. Insets and large-to-small-diameter changes will produce predictable echoes at screen locations corresponding to their distance, and sometimes additional mode-converted echoes caused by beam spreading and side wall bounces will be present. The inspector must note the position of these fixed indications and then look for localized echoes that appear against that background. He or she must also be aware of dead zones not reached by the sound beam due to the "shadow" of diameter changes, although frequently testing from both ends eliminates this problem. In some cases involving stepped diameters, low-angle longitudinal wave wedges are used to aim the sound beam at a specific point of interest, such as a corner that is known to be susceptible to cracking.

Forgings of all sizes can be inspected for internal flaws such as piping, laminar cracking, and ruptures. Testing is commonly done with straight beam transducers, often from two directions, to permit the detection of discontinuities aligned both parallel with and perpendicular to the surface of the part. Surface-breaking cracks are most easily detected through eddy current inspection as a supplement to ultrasonic testing.

7.3 Spot Welds and Braze Joints

Spot welding is a common technique for joining two pieces of metal, usually thin sheets or plates, by means of a series of small circular tack joints approximately 2.5 mm to 6.5 mm (0.100 in. to 0.250 in.) in diameter. The process is widely used in the automotive industry for body assembly and some chassis joints and by other types of sheet metal fabricators such as appliance and metal furniture makers. Spot welds are commonly tested with small, high-frequency delay line transducers (typically 15 MHz or 20 MHz) with elements whose diameter approximates that of the weld.

The most commonly encountered problems with spot welds are lack of fusion, an undersized nugget, or a stick weld (fused but mechanically weak due to poor nugget formation). These conditions can be identified by comparing echo patterns with the pattern of multiple echoes obtained from a good weld of similar geometry.

Spot Weld Echo Patterns

Good Weld

There will be a characteristic echo pattern associated with a good weld, in which the spacing between echoes will be proportional to the thickness of the weld, and the decay rate (the rate at which successive echoes decrease in amplitude) will be related to the attenuation within the nugget. This pattern becomes the reference for further tests.

Undersized Weld

In the case of an undersized weld, a portion of the sound beam will reflect from the total thickness of the two metal sheets, while a portion reflects from a single thickness. This creates a pattern in which smaller peaks representing single sheet thickness appear between the larger and more widely separated peaks representing the full weld thickness.

Stick Weld

A stick weld is a condition in which the metal sheets are fused, but because of insufficient heating the weld nugget is not fully formed. The echo decay rate will change, with larger peaks appearing on the screen and a smaller drop off in amplitude between any two successive peaks.

No Weld

If there is no fusion between the two pieces of metal (a "no weld" or "unweld" condition), then the successive echoes will be much closer together and larger in amplitude.

The EPOCH™ 650 portable flaw detector supports a template storage software option that enables the user to store and recall waveforms for on-screen comparison. Saved templates can be dynamically toggled on and off for fast waveform comparison. This software is particularly useful for spot weld inspections.
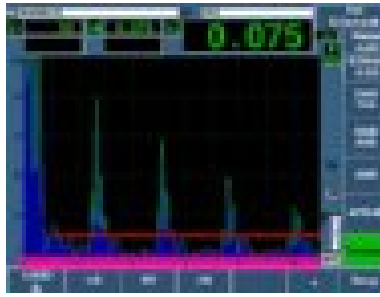
Once an example good weld is identified, the user can quickly store the waveform, which can be superimposed over a live waveform for comparison.
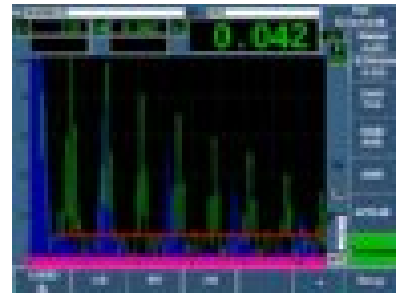
Previously saved waveform templates can be immediately recalled with the press of a button for easy comparison.

Brazing is a common process for joining sections of small-diameter metal tubing and certain other small metal parts such as electrical contacts. It bonds two pieces of metal using a metallic filler that is melted and then flowed into the space between them by capillary attraction. Braze joints are typically tested using a straight beam test that monitors the echo's amplitude from the inside surface of the outer metal part. Small-diameter delay line transducers are commonly used. In the case of a good braze joint at the test point, the metal-to-metal bond will return a relatively small reflection, while an air gap will return a much larger one. These levels are established in each case by setting up on samples representing known brazed and unbrazed conditions. The example below shows a test of a 12.5 mm (0.5 in.) copper tubing braze using a 20 MHz delay line transducer. The gate marks the joint depth. If there is fusion, the echo at that point is very small, and if there is no fusion, it is large.

Braze present, small echo in gate

No fusion, large echo in gate

7.4 Castings

In the casting process, a variety of internal discontinuities can occur in both ferrous and nonferrous metals. These include voids, porosity, inclusions, and cracks. All these conditions produce ultrasonic indications that can be identified by a trained operator using an ultrasonic flaw detector with appropriate transducers.

The granular nature of ferrous and nonferrous castings presents a challenge to ultrasonic flaw detection because of the reflections generated by grain boundaries, with the amount of grain scatter noise increasing as grain size increases. Additionally, the rough surface typically found on sand castings impairs sound coupling and reduces echo amplitude. These factors will determine the minimum detectable defect size in any given test. For this reason, it is important to pay careful
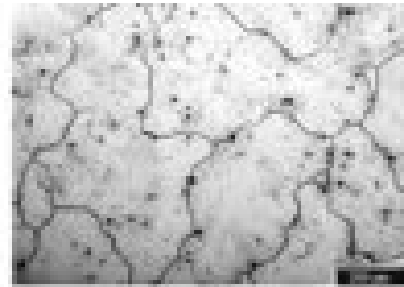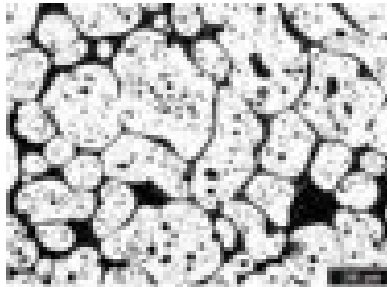

attention to transducer selection and instrument setup, including receiver bandpass filtering. Frequently, dual element transducers at frequencies between 1 MHz and 5 MHz optimize void resolution and scatter noise. The recommended procedure is to optimize transducer selection and setup with the aid of reference standards that represent samples of the parts to be inspected and that contain known defects that have been identified by destructive testing,

radiography, or other non-ultrasonic techniques. The indications from these known defects may then be stored and compared with indications from test pieces.

The example to the right shows a typical mid-wall porosity indication in a 30 mm (1.2 in.) thick iron casting, detected with a 2.25 MHz dual element transducer. An echo appears in the gated region and the back wall echo amplitude is reduced.

Good area, back wall echo only

Porosity indication in gate

Crack test procedures must always be developed with respect to the specific geometry of the casting and the location, size, and orientation of suspected cracks using appropriate reference standards containing known or artificially induced defects. Straight beam transducers are used when the crack face is parallel to the transducer coupling surface and angle beams are used when the crack is perpendicular or tilted with respect to the coupling surface.

Another common ultrasonic application in the foundry industry is measuring nodularity (graphite distribution) in cast iron to check the casting process. Graphite's microstructure within cast iron has major effects on the casting's mechanical properties. There is a predictable relationship between nodularity and sound velocity, and sound velocity can be measured with both ultrasonic flaw detectors and thickness gauges.

7.5 Manufacturing Applications

Manufactured parts represent a wide category of applications with varying materials and geometries. The applicability of ultrasonic flaw detection depends on the specific part geometry and material and the type of flaws that are likely to occur, so potential applications must be evaluated on an individual basis. In many cases, ultrasonic flaw detection can provide a reliable method of characterization. Common examples include:

Manufacturing welds — This is a broad category consisting of manufactured assemblies made by joining two or more metal parts. Laser welds and similar techniques used to join sections of metal can frequently be tested, although the geometry must be favorable. Consult Olympus for details.

Friction welds — These are welds in which metal or plastic parts are joined using heat generated by mechanical friction while the surfaces are pressed together. In many cases, friction welds can be inspected with ultrasonics. The inspector needs to consider the relative acoustic impedances of the materials being joined as well as the specific joint geometry.

Gear welds — Small angle beams or contoured delay line transducers can often be used to verify the depth of penetration in laser welds joining the outer ring and inner hub of large gear assemblies.

Babbitt bearings — Bonding between Babbitt metal liners and bearing shells can be tested with contoured delay line transducers. Voids in the cast Babbitt can also be located.

Thermal fusion joints in plastic parts — Fusion in plastic assemblies can usually be tested with small, straight beam transducers as long as the fusion plane is parallel to the outside surface.

7.6 Fiberglass and Composites

Ultrasonic flaw detection is not limited to metals. As the use of fiberglass and composites in manufacturing increases, so does the need to inspect these materials for structural flaws such as delaminations and impact damage. Both problems can usually be identified through ultrasonic testing. Major users include the aerospace, wind power, marine, and automotive industries as well as manufacturers of fiberglass tanks and other structures.

Low-frequency straight beam transducers (2.25 MHz, 1 MHz, and often 500 KHz) are normally used for testing fiberglass since it often has a high degree of sound scattering. Thicknesses of 75 mm (3 in.) and greater can typically be tested with appropriate transducers and instrument setups. In most cases the procedure involves identifying the back wall echo from the test piece and then looking for indications appearing ahead of the back wall. Scatter noise will commonly be present, so detectable laminar flaws will be those whose echo response is greater than the background scatter. The example below shows a test of a 45 mm (1.78 in.) fiberglass plate. The waveform shows a back wall echo toward the right side of the screen. In the waveform, the large indication at a depth of 39 mm (1.5 in.) comes from the visible delamination. All other peaks represent internal scattering.
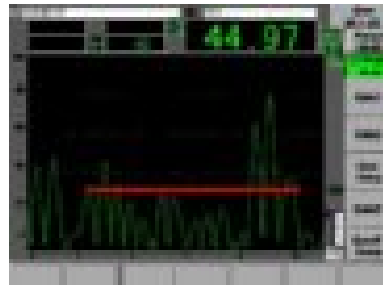
Carbon fiber composites are usually more transmissive than fiberglass, so they can be tested at frequencies up to 5 MHz for better resolution of laminar defects near the front and back surfaces. This is important in applications like detecting impact damage in aircraft parts, where solid laminate aircraft composites can be internally damaged by impacts in a way that is not visible on the outer surface. The example below shows the detection of an inserted artificial disbond in a 3.5 mm (0.140 in.) graphite/epoxy aircraft panel. The insert is located less than 0.5 mm (0.02 in.) from the back wall, but it can be identified in this test with a 5 MHz broadband delay line transducer as a small shift in the position of the echo.

Back wall echo to rthe right of the gate   Laminar defect echo in the gate

Honeycomb composites are more challenging because of the large amount of air they contain. Through-transmission testing with conventional transducers can detect skin separation and core damage, but this is typically done by automated scanning systems during manufacturing and is not a practical field test. But there are also advanced methods for one-sided ultrasonic testing of carbon fiber as well as honeycomb composites, including resonance testing, mechanical impedance testing, and Lamb wave pitch/catch testing. In the case of honeycomb, both skin separation and crushed cores can be identified from one side of the part. These advanced methods require specialized equipment such as the Olympus BondMaster™ multimode bond tester.

8.0 Sizing Techniques

8.1 DAC and TVG

Common Sizing Techniques

This section contains descriptions of some common techniques used for sizing reflectors with the aid of software incorporated in contemporary digital flaw detectors. For full details on how to set up any of these functions, consult your specific instrument's operating manual.

DAC and TVG

A distance amplitude correction (DAC) curve is used to plot the variation in amplitude between reflectors of the same size at varying distances from the transducer. Such reflectors produce echoes whose amplitude in the far field typically decreases as the sound beam travels through the test piece due to attenuation and beam spreading. A DAC curve graphically compensates for material attenuation, near-field effects, and beam spreading. In a DAC setup, the echo amplitude from reflectors that are the same size as those used for calibration will match the curve height no matter what their depth or distance. Similarly, reflectors larger or smaller than those used for calibration will produce echoes above or below the curve.

Time varied gain (TVG) is a related form of presentation that compensates for the same acoustic factors as DAC. Instead of drawing a curve across the display that follows the reference reflector peaks downward as sound is attenuated, TVG increases gain as a function of time (sound path length) to bring all the reference echoes to the same height, typically 80%. It is important to note that in a TVG display, instrument gain varies across the screen even though a single gain value is typically listed. Many modern flaw detectors enable the user to toggle between DAC and TVG displays within a single setup.

Both DAC curves and TVG are commonly set up using a series of reference reflectors that represent a given reflector size at different depths. These are commercially available as distance/amplitude calibration block sets, or users can create their own. Some instruments also enable users to generate DAC/TVG profiles electronically by inputting the gain directly as a function of distance.
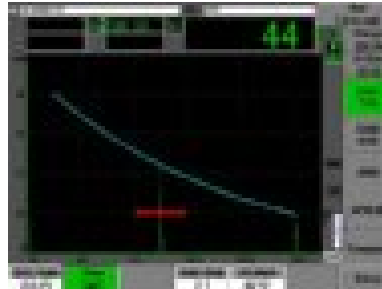
DAC view

TVG view

In the example above, the blue DAC curve represents the plotted amplitude of steel back wall reflectors at distances of 20 mm to 200 mm (0.8 in. to 7.9 in.). The 100 mm (3.9 in.) reflector indication mid-screen matches the curve height. Switching to a TVG view, the gain varies from left to right across the screen so that all back wall reflectors within the calibrated range match the height of the reference line.
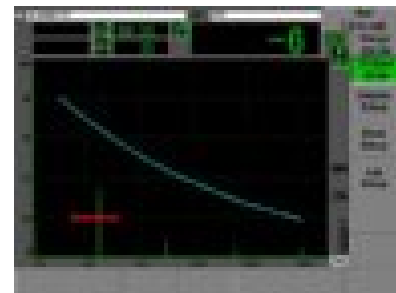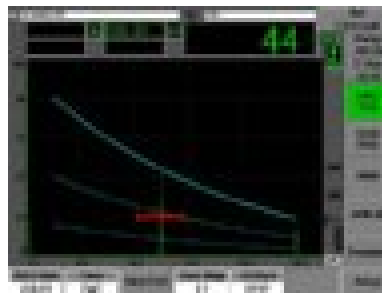
It is also possible to generate multiple DAC curves. In the example above, the highest curve represents a back wall reflector and the others represent -6 dB and -14 dB, respectively, below the reference level (ASTM III format).

8.2 DGS/AVG

DGS/AVG

DGS is a sizing technique that relates the amplitude of the echo from a reflector to that of a flat-bottom hole at the same depth or distance. This is known as the equivalent reflector size or ERS. DGS is an acronym for distance/gain/size and is also known as AVG from its German name, abstand verstarkung grosse. In the past, this technique involved manually comparing echo amplitudes with printed curves. However, modern digital flaw detectors can draw the curves following a calibration routine and automatically calculate the ERS of a gated peak. The generated curves are derived from the calculated beam spreading pattern of a given transducer based on its frequency and element diameter using a single calibration point. Material attenuation and coupling variation in the calibration block and test specimen can be accounted for. DGS is primarily a mathematical technique originally based on the ratio of a circular probe's calculated beam profile and measurable material properties to circular disk reflectors. The technique has since been further applied to square element and even dual element probes, although, for the latter, curve sets are empirically derived. It is always up to the user to determine how the DGS calculations relate to actual flaws in real test pieces.

An example of a typical DGS curve set is shown below. The uppermost curve represents the relative amplitude of the echo from a flat plate reflector in decibels, plotted at various distances from the transducer, and the curves below represent the relative amplitude of echoes from progressively smaller disk reflectors over the same distance scale.
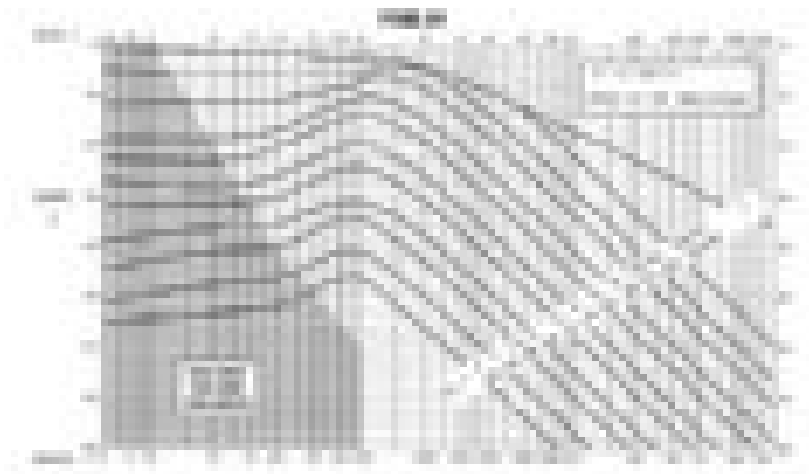

As implemented in modern digital flaw detectors, DGS curves are typically plotted based on a reference calibration off a known target, such as a back wall reflector or a flat-bottom hole, at a given depth. From that one calibration point, an entire curve set can be drawn based on probe and material characteristics. Rather than plotting the entire curve set, instruments will typically display one curve based on a selected reflector size (registration level) that can be adjusted by the user. In the example below, the upper curve represents the DGS plot for a 2 mm (0.08 in.) disk reflector at depths from 10 mm (0.4 in.) to 50 mm (2 in.). The lower curve is a reference that has been plotted 6 dB lower. In the screen, the red gate marks the reflection from a 2 mm diameter flat-bottom hole approximately 20 mm (0.8 in.) deep. Since this reflector equals the selected registration level, the peak matches the curve at that depth. In the screen, a different reflector at a depth of approximately 26 mm (1 in.) has been gated. Based on its height and depth in relation to the curve, the instrument calculated an ERS of 1.5 mm (0.06 in.).
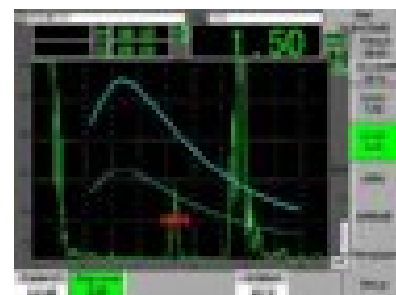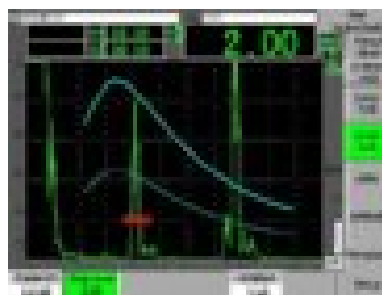
8.3 AWS D1.1

AWS D1.1

The American Welding Society Structural Welding Code section D1.1 defines an established technique for classifying discontinuities in welds according to a "D rating" that is calculated as follows:

$$A - B - C = D \text{ where}$$

A = Discontinuity indication level in dB

B = Reference indication level in dB

C = Material attenuation factor, (2x [soundpath length in inches – 1 in.]) expressed in dB

The inspector then compares the calculated indication D rating to an acceptance/rejection table provided by AWS to classify the severity of the discontinuity. As an inspection proceeds, the operator develops an AWS report that lists the variables above as well as transducer information, discontinuity length and location, and the inspector's evaluation.

Modern flaw detector software simplifies this process by incorporating the D-rating calculation into the display and recording A, B, C, and D values in stored test records. In setup, the operator records a reference amplitude level B from a specified side-drilled hole reflector. When testing, the instrument measures indication amplitude and sound path length to obtain values for A and C and then calculates the D-rating, which can be either positive or negative depending on whether the reflector echo is smaller or larger than the reference echo used in the setup. In the example below, the flaw indications in the red gate have D-ratings of -1.22 and +5.44, respectively, indicating relatively large and small reflectors.
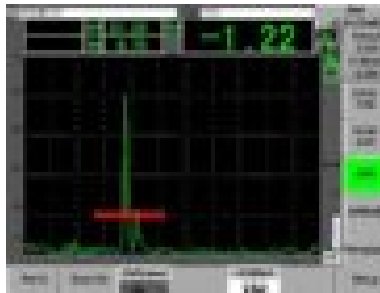
8.4 API

API 5UE

The American Petroleum Institute Recommended Practice 5UE is used to inspect newly fabricated steel pipe for ID cracking. The API code describes two crack sizing methods for characterization of ID cracking— the amplitude comparison technique (ACT) and the amplitude-distance differential technique (ADDT). Software has been developed to perform the calculations used in the ADDT sizing technique.

The test is based on the following equation:

$$di = A_{max} \times (T_2 - T_1) \times k$$

where:

di = The size of the imperfection
A_{max} = Maximum amplitude returned from the defect area (usually 80%)
t_1 = 6 dB drop point from the leading peak of Amax (distance or time)
t_2 = 6 dB drop point from the trailing peak of Amax (distance or time)
k = A constant calculated from calibration to a reference notch

In ADDT testing, when a crack has been located during angle beam testing, the operator finds the peak amplitude point and sets it to 80% screen height. This indication is designated as Amax. The probe is then moved toward the crack until the signal has dropped by 6 dB or 50%, and this position is noted as T1. It is then backed away from the crack to a point on the other side of the echo envelope where the signal has dropped by 50%, and this position is designated as T2.

In a typical software implementation, the operator simply scans the probe across the indication while recording an echo envelope. The k constant is established in an initial reference calibration on a notch of known size. The software then identifies the Amax peak and the T1 and T2 points for each collected indication (marked with red dots on the edges of the envelope below) and calculates the "di" value (0.13 in. in the example below).
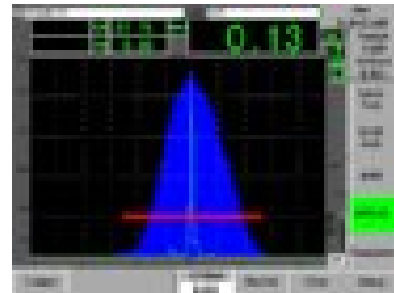
8.5 Curved Surface Correction (CSC)

Curved Surface Correction (CSC)

Curved surface correction (CSC) software is used to provide accurate measurement of reflector depth and position when working on curved test pieces. In the case of common flat plate tests and axially-oriented tests of pipes and similar products, leg length, reflector depth, and surface distance can be calculated through simple trigonometry. But when testing a curved part in the circumferential direction, these formulas become inaccurate due to the curvature that effectively causes reflectors to drop away from the probe, lengthening the sound path and changing the reflection angle at the inside surface of the part. For example, compare these measurements with a 45° beam in flat and curved plates that are both 20 mm (0.8 in.) thick. In a flat plate, an echo at a sound path length of 35 mm (1.4 in.) corresponds to

To correct for curvature, a number of mathematical relationships can be applied based on the angles, measured sound path, and dimensions defined below. Using software, these formulas enable the proper calculation of surface projection and the vertical depth of flaws. The operator inputs incident angle, part thickness, and part diameter, and the instrument applies appropriate trigonometric equations to adjust the measured sound path.

a reflector at a depth of 15.2 mm (0.6 in.) located 24.8 mm (1 in.) forward from the beam exit point. But without correction, the same 35 mm sound path in a 200 mm (7.9 in.) diameter pipe (100 mm (3.9 in.) OD radius) will produce

incorrect dimensional measurements corresponding to a reflector 19.2 mm (0.75 in.) below the OD surface and 31.7 mm (1.2 in.) along the surface from the beam exit point to the point over the reflector.

Equation Parameters:

S = Surface Distance
β = Angle of Refraction
ω = Sound Path Distance
t = Thickness
R_i = Inside Radius
R_o = Outside Radius
β_{max} = Maximum Angle of Refraction
κ = Angle of Reflection at ID
ϕ = Projection Angle
D = Depth of Reflector

Projection Angle at ID (first leg)

$$\phi = \sin^{-1}\left(\frac{R_o}{R_i}\sin\beta\right)$$

Sound path distance a half skip

$$\omega = R_i\left(\frac{\pi\kappa\beta}{\sin\beta}\right)$$

Depth of reflector D

$$D = R_o - \sqrt{\omega^2 + R_o^2 - 2\omega R_o \cos\beta}$$

Surface distance S

$$S = \frac{\pi R_o}{180}\left| \sin^{-1}\left(\frac{\omega}{R_o}\sin\beta\right) - \beta \right|$$

(valid for first leg test $R_o < t$)

Maximum angle of refraction for a given wall thickness (angle of impingement)

$$\beta_{max} = \sin^{-1}\left(\frac{R_i}{R_o}\right)$$

SCOPPPLES	CSC Off	CSC On	Physical Measurement
Actual Path	1.14	1.14	N/a
Depth	0.14	0.27	0.22
Surface distance	0.9	1.08	1.05

The example above shows the effect of CSC software on the measurement shown in the photograph. With CSC off, the displayed depth and surface distances are too low, and with CSC on, the displayed numbers are corrected for the curvature.

9.0 Advanced Techniques

9.1 Tip Diffraction

Wave diffraction is a general phenomenon in ultrasonics. The sharp tip of a well-defined internal defect like a crack will diffract an incident ultrasonic beam, creating a spherical wave front whose arrival at the probe can be used to locate the tip and measure the depth of the crack. Common angle beam transducers are used for this test. Higher transducer frequencies produce the strongest diffraction signals.

In the example below, a 5 MHz transducer with a 45-degree wedge is used to measure the depth of a 5 mm (0.2 in.) tall crack on the bottom of a 12.5 mm (0.5 in.) thick steel plate. The waveform shows the peaked-up indication from the bottom corner of the crack. The probe is then moved to the right per the drawings, and the tip diffraction

signal appears ahead of the corner indication. When the tip signal has been peaked, a trigonometric calculation based on the sound path length provides the distance to the top of the crack.
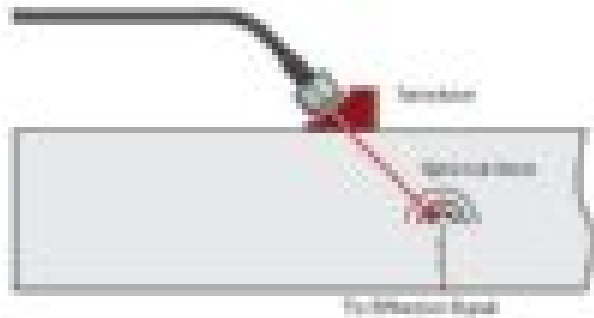
Corner indication

Tip diffraction and corner indications

9.2 CDS/Creeping Waves

CDS wedges are specialized plastic wedges used to detect cracks and determine whether a crack is ID connected. This technique can further indicate if the crack is located in the inner, middle, or outer third of the part thickness. CDS stands for creeping-direct-shear, also known as the 30-30-70 technique. CDS wedges use single element transducers to simultaneously generate three waves in the test piece.
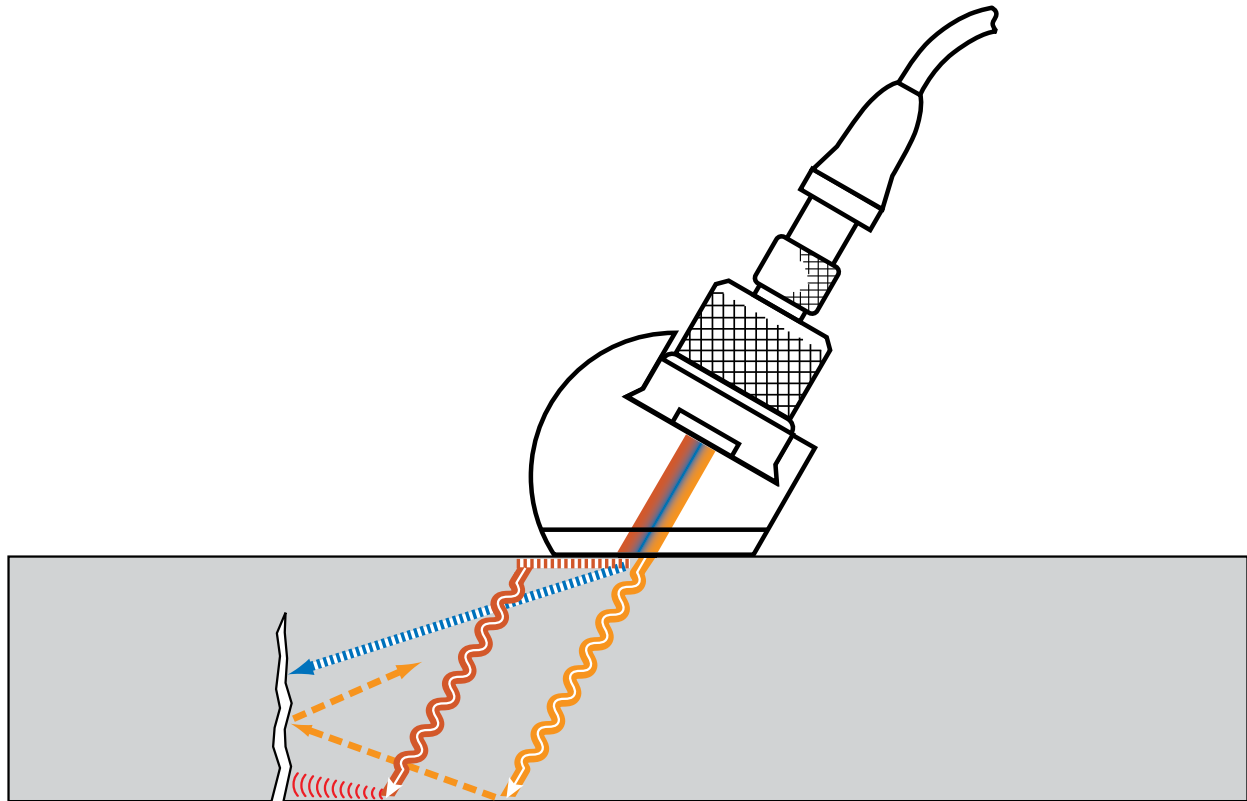
1. An OD creeping wave creates a 31.5-degree indirect shear wave (red path in drawing above), which mode converts to an ID creeping wave. This will produce a reflected signal from all ID connected cracks.

2. A 30-degree shear wave (orange path) will reflect off the material ID at the critical angle to create a 70-degree longitudinal wave. A signal will be received by the transducer from cracks that extend into the mid-wall region or deeper.

3. A 70-degree direct longitudinal wave (blue path) will create a tip diffraction signal from very deep cracks.

The presence or absence of these signals is essential to interpreting the test results. For a detailed discussion of typical test setup and interpretation, see Detection and Sizing Techniques of ID Connected Cracking.

9.3 B-Scan

The single value B-scan display presentation that was described in Section 3.5 can be used to profile the inner surface of a part, as in corrosion inspections, or to plot the relative depth of laminar flaws. As noted earlier, a single value B-scan plots the depth of reflectors with respect to position as the transducer is moved across the test piece. The position tracking is typically done using electromechanical devices called encoders. These encoders are used in fixtures that are either manually scanned or in automated systems that move the transducer by a programmable motor-controlled scanner.

The example below shows the depth profile of a reference block that contains drilled holes and corroded spots. The display shows the current A-scan, the scanned profile, and the current thickness reading. Single value B-scans can typically be stored and played back for later analysis.
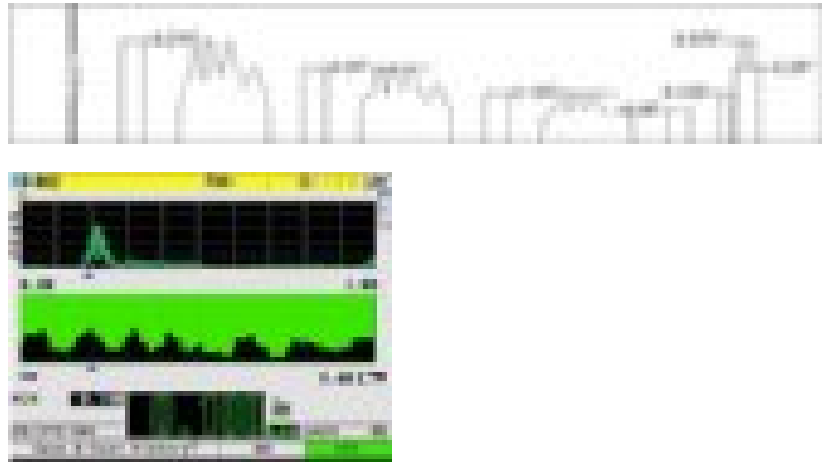
9.4 Dual Element Angle Beams (TRL Testing)

Welds in coarse-grained cast steel, such as in nuclear pressure vessels, are often difficult to inspect with conventional shear wave angle beam probes due to the high level of grain scatter noise they generate. TRL (transmit-receive-longitudinal) probes, as the name indicates, use separate transmit and receive elements and generate refracted longitudinal waves rather than shear waves. The overlapping beam footprints of the T and R sides create a natural focal zone where the sensitivity is maximized, while the longer wavelength of longitudinal waves reduces grain scattering. In addition, the use of separate T and R elements minimizes unwanted wedge noise at high gain. While the focusing effect limit maximum range, TRL probes are highly sensitive to reflectors located within the focal zone and are well suited for certain difficult applications.

9.5 High-Temperature Testing

While most ultrasonic flaw detection is performed at normal environmental temperatures, some situations involve test pieces that are hot, as in process industries where hot metal tanks or pipes must be tested without a shutdown. Conventional ultrasonic transducers can tolerate temperatures up to approximately 50° C, or 125° F. At higher temperatures, they will eventually suffer permanent damage due to internal disbonding caused by thermal expansion. If the material being tested is hotter than approximately 50° C or 125° F, then high-temperature transducers and special test techniques should be employed.

Transducers and wedges

With respect to straight beam testing, high-temperature dual element transducers are commonly used in corrosion survey applications. High-temperature duals can also be used in many cases involving straight beam inspection of plates and bars and for finding laminar flaws in tanks and pipes. For small or thin parts, special high-temperature delay line transducers are also available.

For angle beam testing, high-temperature wedges are available. These are used with standard transducers to provide thermal insulation. It is important to note that with any high-temperature wedge, sound velocity in the wedge material will decrease as it heats up, and the refracted angle in metals will increase as the wedge heats up. If this is of concern in a given test, the refracted angle should be verified at actual operating temperature. Practically, thermal variations during testing will often make it difficult to precisely determine the actual refracted angle.

Material properties

Sound velocity in all materials changes with temperature, slowing down as the material heats up. In steel, this velocity change is approximately 1% per 55 °C or 100 °F change in temperature. (The exact value varies depending on the alloy.) In plastics and other polymers, this change is much greater and can approach 50% per 55 °C or 100 °F change in temperature up to the melting point. If a temperature/velocity plot for the material is not available, then a velocity calibration should be performed on a sample of the test material at the actual test temperature.

Similarly, sound attenuation in all materials increases with temperature. In typical fine-grained carbon steel alloys, attenuation at 5 MHz increases by more than 12 dB per 100 mm (3.9 in.) sound path (equivalent to a round trip path of 50 mm (2 in.) each way) between room temperature and 500 °C (930 °F). This effect can require the use of significantly increased instrument gain when testing over long sound paths at high temperature and can also require adjustment to distance/amplitude correction (DAC) curves or TVG (time varied gain) programs that were established at room temperature. The effect is much more pronounced in plastics than in metals or ceramics.

The example below shows the changes in velocity/transit time and attenuation when a 12.5 mm (0.500 in.) steel block is heated to 300 °C (570 °F). Pulse transit time increases from 4.37 µs to 4.59 µs, and an additional 18.2 dB of gain is needed to equalize the echo amplitude. The change in transit time would represent a measurement error of about +5% or 0.63 mm (0.025 in.) if the operator does not recalibrate velocity for the hot test piece.
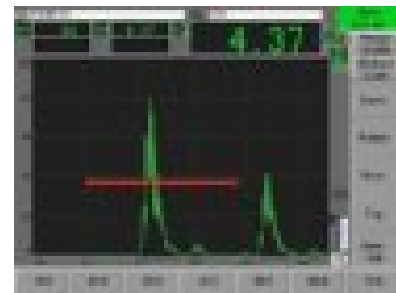
Room temperature, 24.5 dB gain
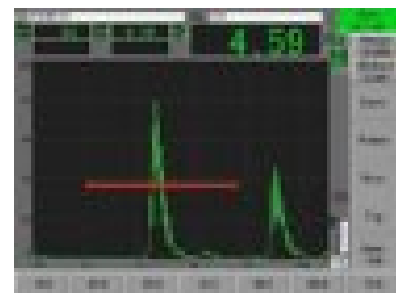
300 °C (572 °F), 42.7 dB gain

Couplants

Most common ultrasonic couplants, such as propylene glycol, glycerin, and ultrasonic gels, will quickly vaporize if used on surfaces hotter than approximately 100 °C (212 °F). Testing at high temperatures requires specially formulated couplants that will remain in a stable liquid or paste form without burning or releasing toxic fumes. These are widely available.

Duty Cycles

All standard high-temperature transducers and wedges are designed with a duty cycle. Although they are insulated, lengthy contact with very hot surfaces will cause significant heat buildup and, eventually, permanent damage to the transducer if the interior temperature becomes hot enough. Surface contact should be as brief as possible followed by a period of air cooling. The ratio of contact time to cooling time becomes more critical at the upper end of a given transducer's specified temperature range. As a general rule, if the outer case of the transducer becomes too hot to comfortably hold with bare fingers, then the transducer's interior is approaching a potentially damaging temperature, and it must be allowed to cool down before testing continues.

For further information on high-temperature ultrasonic testing, see High-Temperature Ultrasonic Testing.

9.6 Phased Array
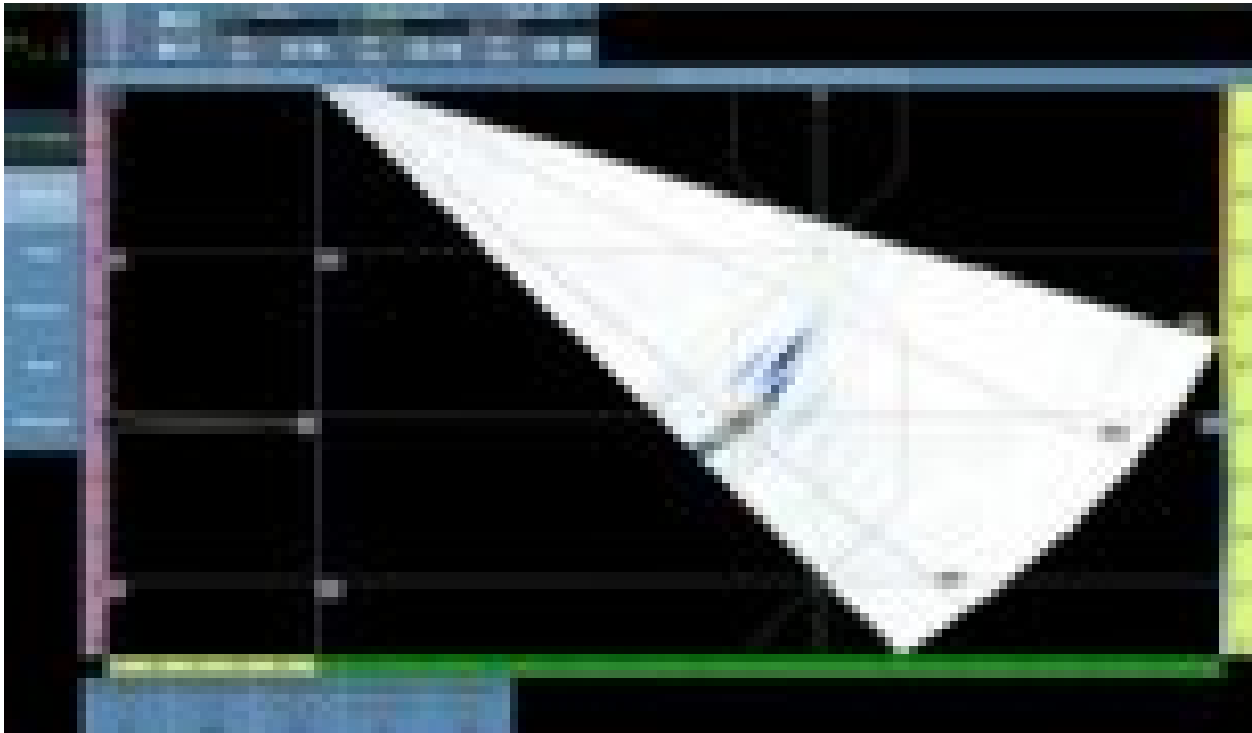
This tutorial has focused on conventional flaw detection using single element and dual element transducers. But as ultrasonic NDT technology develops, phased array systems that use sophisticated array probes with as many as 256 or more elements are becoming common since they provide new levels of information and visualization in applications such as weld inspection, bond testing, thickness profiling, and in-service crack detection.

The benefits of phased array technology over conventional UT come from its ability to use multiple elements to steer, focus, and scan beams with a single transducer assembly. Beam steering, commonly referred to sectorial scanning, can be used for mapping components at appropriate angles. This can greatly simplify the inspection of components with complex geometries. The small footprint of the transducer and the ability to sweep the beam without moving the probe is helpful when there is limited access for mechanical scanning. Sectorial scanning is also typically used for weld inspection. The ability to test welds with multiple angles from a single probe greatly increases the probability of detection. Electronic focusing permits optimizing the beam shape and size at the expected defect location, further increasing the probability of detection. The ability to focus at multiple depths also improves the ability to size critical defects for volumetric inspections. Focusing can significantly improve the signal-to-noise ratio in challenging applications, and electronic scanning across many groups of elements enables C-scan images to be produced very rapidly.

For further information on phased array testing, Olympus has a brief Introduction to Phased Array and a comprehensive Phased Array Tutorial.

10. Glossary

Glossary of Flaw Detection Terms

A
Acoustic Impedance
Acoustic Interface
Acoustic Velocity
Amplifier
Amplitude
Analog Output
Angle Beam Transducer
A-Scan
Attenuation

B
Backwall Echo
BackGround Noise
Beam-Index Point (BIP)

C
Couplant
Critical Defect
Cross Talk

D
Damping (Control)
DampIng Material
Decibel (dB)
Delay Control
Detectability
Distance Amplitude Correction (DAC)
Distance Gain Sizing (DGS)
Dual Element Probe
Dynamic Range

E
Excitation Pulse

F
Filter
First CrItical Angle
Flaw
Frequency

G
Gain
Gate

H
Hertz (Hz)

I
Immersion Testing
Incidence, Angle Of
Indication
Indication (Defect) Level

L
Leg
Linearity, Vertical Or Amplitude
Linearity, Horizontal Or Distance
Los
LongiTudinal Wave

M
Main Bang
Mode Conversion

P
Peak Memory
Peaking Up
Penetration
Piezoelectric Materials
Pitch-Catch
Probe
Pulse Repetition Frequency (PRF)

R
Range
Receiver
Rectification
Reference Echo
Reference Gain (Reference Level)
ReFerence Line
Reference Reflector
Refraction, Angle Of
Reject (Control)
Resolution

S
Scanning Gain
Second Critical Angle
Sensitivity
Signal-To-Noise Ratio
Single Element Probe
Skip Distance
Sound Beam
Sound Path Distance
Straight Beam Probe (Normal Beam Probe)
Surface Wave

T
Through Transmission
Time Varied Gain (TVG)
Transducer
Transmitter

U
Ultrasonic

V
V-Path

W
Wavelength

Z
Zero Offset

A

ACOUSTIC IMPEDANCE
A material property defined as the product of sound velocity (c) and the material's density (d).

ACOUSTIC INTERFACE
The boundary between two materials of different acoustic impedance.

ACOUSTIC VELOCITY
The speed of sound in a test material. Different wave modes such as longitudinal and shear will have different velocities.

AMPLIFIER
An electronic device that increases the strength of a signal, using power from a source other than the input signal.

AMPLITUDE
The height of an indication on a waveform display, measured from the lowest to the highest point on the indication. This corresponds to relative signal strength and is often referred to as %FSH (percent full screen height).

ANALOG OUTPUT
A data output format consisting of a DC voltage whose amplitude corresponds to a measured parameter such as echo amplitude or depth.

ANGLE BEAM TRANSDUCER
A transducer that transmits or receives acoustic energy at an angle to the surface, to generate refracted shear waves or surface waves in the part being inspected.

A-SCAN
The most common waveform display format, plotting signal amplitude versus distance. An A-Scan shows the pulse travel time in the horizontal direction (left to right), representing the corresponding sound paths, and the echo amplitude in the vertical direction.

ATTENUATION
The loss in acoustic energy that occurs between any two points of travel. This loss may be due to absorption, reflection, scattering, or other phenomena.

B

BACKWALL ECHO
The echo received from the side of the test piece opposite the side to which the transducer is coupled. This echo represents the thickness of the test piece at that point.

BACKGROUND NOISE
Extraneous signals caused by sources within the ultrasonic testing system and/or the material being tested.

BEAM-INDEX POINT (BIP)
For an angle beam probe, the point where the sound leaves the wedge and enters the specimen.

C

COUPLANT
A material (usually a liquid or gel) used between the transducer and the test piece to eliminate air from this space and facilitate the coupling of sound waves into and out of the specimen.

CRITICAL DEFECT
Either the largest tolerable defect or the smallest intolerable defect in a test piece. The critical defect size is usually given by a specification or code.

CROSS TALK
An unwanted condition affecting dual element transducers in which acoustic energy travels from the transmitting element to the receiving element by a route other than the intended path through the test piece.

D

DAMPING (CONTROL)
A variable resistance across the pulser circuit output that shapes the excitation pulse. Typically it is used to change pulse characteristics to optimize either penetration (low damping) or near surface resolution (high damping).

DAMPING MATERIAL
Any epoxy or other high attenuation material used in the transducer to shorten the ringing time of the piezoelectric element.

DECIBEL (dB)
A unit which compares levels of power, commonly used to express relative sound intensities in ultrasonic testing. Two amplitude levels V1 and V2, expressed as either voltages or screen percentages, are said to differ by n decibels where:
dB = 20 log (V2 / V1)

DELAY CONTROL
Software function that introduces an adjustable time period between the excitation pulse and the start of the sweep across the data display.

DETECTABILITY
The ability of a test system (instrument and transducer) to detect or "see" a given size reflector.

DISTANCE AMPLITUDE CORRECTION (DAC)
A method of flaw sizing that plots an on-screen curve representing the echo amplitude from a known size reflector at varying distances from the transducer. This curve compensates for the loss of energy due to beam spreading and attenuation.

DISTANCE GAIN SIZING (DGS)
A sizing technique that mathematically relates the amplitude of the echo from a reflector to that of a flat bottom hold at the same depth or distance. The generated curves are derived from the calculated beam spreading pattern of a given transducer, based on its frequency and element diameter, and adjusted for material attenuation.

DUAL ELEMENT PROBE
A transducer containing two piezoelectric elements, one which transmits and one which receives.

DYNAMIC RANGE
The range of gain or signal amplitude that can be displayed on a given instrument.

E

EXCITATION PULSE
The pulse of electrical energy sent by the pulser to the transducer, sometimes known informally as the main bang. Both spike (broadband) and square wave (tuned) excitation pulses are commonly used.

F

FILTER
Receiver function that passes selected frequency components of a signal and rejects others, used to improve signal-to-noise, near surface resolution, and dynamic range. Filters may be high pass, low pass, narrowband, or broadband.

FIRST CRITICAL ANGLE
In angle beam or immersion testing, the minimum incident angle in the wedge or water path at which the refracted longitudinal wave disappears from the test piece.

FLAW
A discontinuity that may be undesirable but does not necessarily call for rejection, depending on procedural requirements.

FREQUENCY
The number of complete cycles per second undergone or produced by an oscillating as body expressed the reciprocal of the period t. $f = 1/t$

G

GAIN
Used in electronics to reference to an increase in signal power, usually expressed as the ratio of the output power to the input power in decibels.

GATE
A software function that selects and marks a portion of the displayed range for measurement of distance or amplitude.

H

HERTZ (Hz)
The unit of frequency, defined as the frequency of a periodic phenomenon of which the period is one second; equal to one cycle per second.
Symbol Hz.
1 kilohertz (kHz) = 103 cycles per second
1 Megahertz (MHz) = 106 cycles per second

I

IMMERSION TESTING
A test method in which a water bath or a water column is used to couple sound energy from the transducer to the test piece. It is commonly used in automated scanning applications.

INCIDENCE, ANGLE OF
The angle between a sound beam striking an acoustic interface and the normal (perpendicular) orientation to the surface at that point. Usually designated by the Greek symbol α (alpha).

INDICATION
A displayed signal signifying the presence of a sound wave reflector.

INDICATION (DEFECT) LEVEL
The amount of gain which must be added to an instrument setup to bring an indication (defect) echo signal to peak at a selected reference level.

L

LEG
In angle beam testing, the path the shear wave travels in a straight line before being reflected by the opposite surface of the material being tested.

LINEARITY, VERTICAL OR AMPLITUDE
The degree to which an ultrasonic instrument responds in a proportional manner to a range of echo amplitudes produced by specified reflectors.

LINEARITY, HORIZONTAL OR DISTANCE
The degree to which an ultrasonic instrument responds in a proportional manner to a range of echo signals produced by specified reflectors at different points in time.

LOS
Acronym for Loss Of Signal.

LONGITUDINAL WAVE
Mode of wave propagation characterized by particle movement parallel to the direction of wave travel.

M

MAIN BANG
Informal term for excitation pulse.

MODE CONVERSION
The change of a portion of sound beam energy into a wave of a different mode due to refraction at incident angles other than zero degrees. In NDT, this usually involves conversion of longitudinal waves into shear waves or surface waves.

P

PEAK MEMORY
A software function that records an echo envelope as the transducer scans across a test piece by capturing and storing on the screen the peak echo amplitude at each pixel location.

PEAKING UP
Maximizing the height of a displayed indication by optimizing the position of the sound beam.

PENETRATION
The ability of the test system to overcome signal amplitude loss across a sound path due to factors like attenuation, scattering, and beam spreading.

PIEZOELECTRIC MATERIALS
A family of materials (such as quartz, lead metaniobate and lead zirconium titanate) that possess the characteristic ability to produce a voltage differential across their faces when deformed by an externally applied mechanical force, and a change in their own physical configuration (dimensions) when an external voltage is applied to them.

PITCH-CATCH
A test method which utilizes separate transmitting and receiving transducers on the same side of the test piece.

PROBE
In ultrasonic testing, an alternate name for transducer.

PULSE REPETITION FREQUENCY (PRF)
The frequency at which an instrument generates an excitation pulse and initiates a data acquisition cycle. Also known as Pulse Repetition Rate.

R

RANGE
The total distance represented by the horizontal display axis.

RECEIVER
The circuits a flaw detector that receive and process returning echoes (as voltages) from the transducer. Typical signal processing includes amplification, filtering, and rectification.

RECTIFICATION
Receiver function that selects display of waveforms as an RF signal with both positive and negative deflections, a full wave rectified signal in which all deflections are displayed as positive, or half wave negative and positive in which only one side of the RF signal is displayed as a positive deflection.

REFERENCE ECHO
The echo from a specified reference reflector.

REFERENCE GAIN (REFERENCE LEVEL)
A gain level established by a test procedure, commonly by setting a reference reflector echo to a specified height.

REFERENCE LINE
A designated percentage of total screen height at which reference echoes and indication echoes are compared.

REFERENCE REFLECTOR
A reflector of known size and geometry at a known distance, such as a flat bottom hole.

REFRACTION, ANGLE OF
The angle with respect to perpendicular of the sound beam in the test material, generated by refraction from the angle of incidence in the wedge.

REJECT (CONTROL)
Also known as suppression, this limits the input sensitivity of the amplifier in the receiver to display only indications greater than a selected height. It is used to reduce or eliminate "grass" or scattering noise from the display.

RESOLUTION
The ability of the test system (instrument and transducer) to distinguish between two reflectors at slightly different depths, or within a given distance of the surface of the test piece.

S

SCANNING GAIN
The amount of gain above the reference level added per procedure to optimize visibility of indications.

SECOND CRITICAL ANGLE
In angle beam or immersion testing, the minimum incident angle in the wedge or water path at which the refracted shear wave disappears from the test piece.

SENSITIVITY
The ability of the test system (instrument and transducer) to detect a given size reflector at a given distance.

SIGNAL-TO-NOISE RATIO
The amplitude ratio between the echo from a given indication and background indications such as grain scattering or instrument noise.

SINGLE ELEMENT PROBE
A transducer containing only one piezoelectric element, which is used to both transmit and receive sound.

SKIP DISTANCE
In angle beam testing, the surface distance which represents one V-path of sound in the material.

SOUND BEAM
The characteristic shape of the ultrasonic wave in a test piece.

SOUND PATH DISTANCE
The distance between the transducer and a reflector. In angle beam and immersion testing, this is commonly measured from the point at which sound enters the test piece. This is sometimes referred to as angular distance in angle beam testing.

STRAIGHT BEAM PROBE (Normal beam probe)
A transducer that transmits sound into the test piece perpendicular to the entry surface.

SURFACE WAVE
A mode of wave propagation characterized by an elliptical movement of the particles on the surface of the specimen as the wave front moves forward, penetrating the specimen to a depth of one wavelength.

T

THROUGH TRANSMISSION
A test method in which the pulses from a transmitting transducer are received by a second transducer on the opposite side of the test piece.

TIME VARIED GAIN (TVG)
A software function that adjusts instrument gain so that the echo amplitude of a given size reflector is displayed at a constant display height regardless of the distance to that given size reflector.

TRANSDUCER
A device that transforms one form of energy into another.

TRANSMITTER
The circuits of a flaw detector that sends the initial pulse voltage to the transducer.

U

ULTRASONIC
Of or relating to frequencies above the human audible range, above 20,000 cycles/s (20 kHz).

V

V-PATH
The angular distance sound travels, measured from the top surface of the test piece to the bottom and reflecting back up to the top surface.

W

WAVELENGTH
The distance between like points on successive wave fronts; the distance between any two successive particles of the oscillating medium that are in the same phase. It is denoted by the Greek letter λ (lambda).

Z

ZERO OFFSET
A time offset between the moment the excitation pulse is generated and the point at which the screen display and measurement begins, typically used to subtract transit time through a wedge, delay line, or wearplate from a depth or distance measurement.

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