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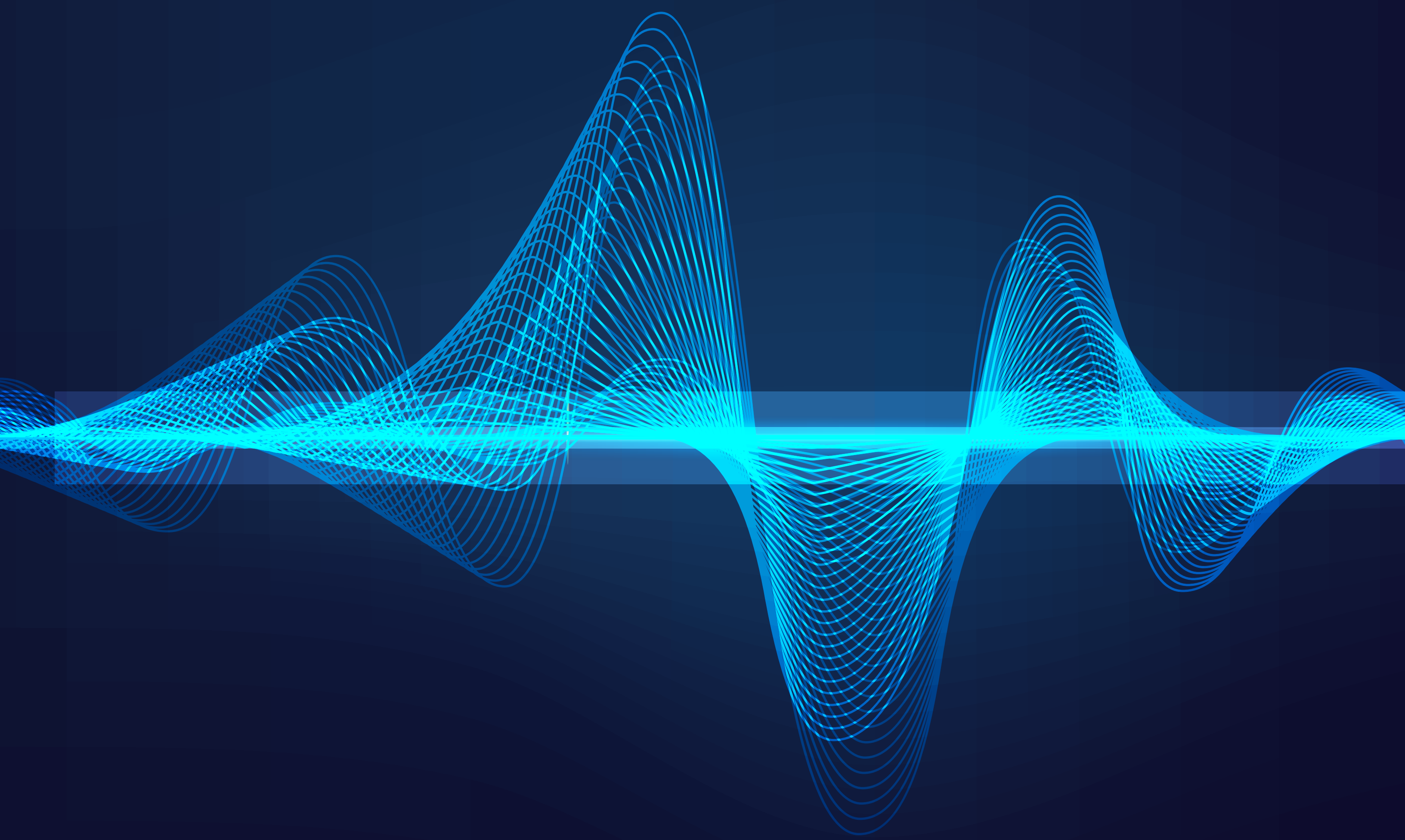
Ultrasonic Thickness Gauge Tutorial



Ultrasonic Thickness Gauge Tutorial

Ultrasonic thickness gauging is a widely used nondestructive technique for measuring the thickness of a material from one side. Just about anything made out of metal, plastic, composite, ceramic, glass, fiberglass, or rubber can be measured. This tutorial provides a basic introduction to the theory and practice of ultrasonic thickness gauging for both newcomers and more experienced users who would like a review. It covers basic ultrasonic theory, how ultrasonic gauges work, how they are used, and discusses many specific gauge applications. Find additional reference information, including a glossary, in the Appendix.

1.0 Introduction

1.1 Introduction to Ultrasonic Thickness Gauges

For more than fifty years, ultrasonic thickness gauges have been used by quality control professionals to measure the thickness of a wide variety of products across a range of industries. This includes inspectors testing critical parts like aircraft turbine blades for wear and maintenance crews checking pipes and tanks for in-service corrosion. As hardware and software development has advanced over the years, ultrasonic thickness gauges have become powerful, reliable, and user-friendly tools. This tutorial describes how they work and what they are used for.

What Are Ultrasonic Thickness Gauges Used For?

Ultrasonic thickness gauges are often used to determine the thickness of a material where an inspector only has access to one side of the part, such as a pipe or tube, or where simple mechanical measurement is impossible or impractical due to the part's size or access limitations. The fact that thickness measurements can quickly and easily be made from one side, with no need to cut parts, is one of the major advantages of this technology.

Virtually any common engineering material can be measured ultrasonically. Ultrasonic thickness gauges can be set up for metals, plastics, composites, fiberglass, ceramics, and glass. In-line or in-process measurement of extruded plastics and rolled metal is often possible, as is the measurement of individual layers or coatings in multilayer fabrications. Liquid levels and biological samples can also be measured. Ultrasonic gauging is always completely nondestructive, with no cutting or sectioning required. The range of measurement can be as large as 0.08 mm (0.003 in.) to 635 mm (25 in.), depending on material and transducer selection. Materials that are generally unsuitable for measurement with conventional ultrasonic gauges include wood, concrete, paper, and foam products.

Ultrasonic thickness gauges work by very precisely measuring how long it takes for a sound pulse that has been generated by a probe called an ultrasonic transducer to travel through a test piece. Because sound waves reflect from material boundaries, timing the echo from the far side of the test piece can be used to gauge its thickness, in the same way that radar or sonar measure distance. Resolution can be as fine as 0.001 mm or 0.0001 in.

Most ultrasonic thickness gauging applications use small, handheld transducers, but some complex geometries as well as in-line testing require noncontact transducers that focus a sound beam through a water column or bath. Measurements are essentially instantaneous and can be recorded on internal instrument data loggers for documentation or analysis.

What Materials Can Be Measured with an Ultrasonic Thickness Gauge?

Ultrasonic gauging can be used to measure corrosion, coatings, and a range of materials, most typically metals, plastics, composites, fiberglass, or ceramic glass.

Corrosion

If undetected over time, corrosion can weaken the structural integrity of metals like beams, bridge supports, and steel pilings. Ultrasonic thickness gauges can be used to nondestructively inspect metals to detect any damage or weakness that corrosion might have caused to metal structures.

Metals

Ultrasonic thickness gauges can be used to measure many metal products, including pipes and tanks, sheets and coils, gun drilling, or tubing. Ultrasonic gauging can be used for quality assurance purposes to help ensure that manufacturing meets industry standards and that a product is safe and strong enough to perform its key function.

Plastics

The use of nonmetallic engineering products like plastics has become more common, increasing the need for wall thickness to be measured for quality control. Ultrasonic testing is now used on bottles and containers, plastic pipes, and fiberglass pipes and boats to help ensure industry standards are accurately met and manufactured materials are safe to use.

Other Materials

Ultrasonic gauging can also be used for a variety of other materials. This includes rubber products, ceramics, glassware, and liquid level, where the user cannot access both sides of the material.

1.2 Benefits of Ultrasonic Thickness Gauging

Ultrasonic thickness gauges offer many benefits over mechanical and optical measurement techniques in a variety of common manufacturing and in-service test applications, supporting quality control, reliability, and condition monitoring in a cost-effective and user-friendly way.

Measurement from one side: Ultrasonic gauges require access to only one side of pipes, tanks, tubing, containers, hollow castings, large metal or plastic sheets, and other test pieces where the inside surface is impossible or difficult to reach.

Completely nondestructive: No cutting or sectioning of parts is required, saving scrap and labor costs.

Highly reliable: Modern digital ultrasonic gauges are highly accurate, repeatable, and reliable.

Versatile: All common engineering materials can be measured with appropriate gauge setups, including metals, plastics, composites, fiberglass, ceramics, and rubber. Most instruments can be pre-programmed with multiple application setups.

Wide measurement range: Ultrasonic gauges are available for measurement ranges as broad as 0.08 mm (0.003 in.) minimum to 635 mm (25 in.) maximum, depending on material and transducer selection. Resolution can be as fine as 0.001 mm or 0.0001 in.

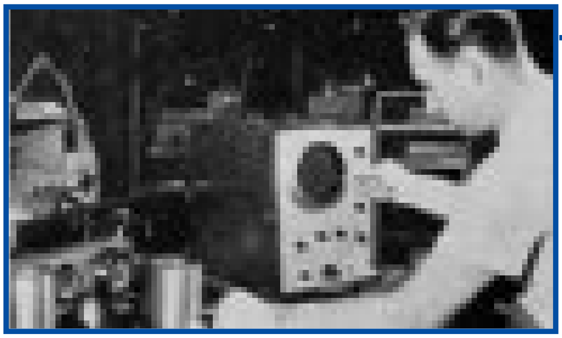
Easy to use: Most ultrasonic gauging applications use straightforward pre-programmed gauge setups and require only minimal operator interaction. While this tutorial discusses many advanced techniques and challenging measurements, advanced training in ultrasonics is not required in most cases.

Instant response: Measurements usually take only one or two seconds per point and are displayed as a digital readout.

Compatible with data logging and statistical analysis programs: Most modern handheld gauges offer both on-board storage for measurement data and USB or RS232 ports for transferring measurements to a computer for record-keeping and further analysis.

1.3 A Brief History of Ultrasonic Thickness Gauging

1950



Early Commercialized Ultrasonic Inspection Equipment

1960

Early Commercialized Ultrasonic Inspection Gauges

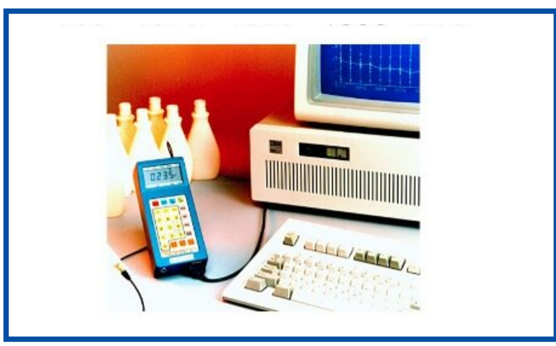
1970

Handheld Thickness Gauges Become Prevalent

1980

Gauges with Onboard Waveform Display

1990



Onboard Data Logging and Computer Interfaces Become Common

1990

First All Digital, Handheld Multipurpose Gauges Introduced

2000

Modern Handheld Digital Gauges

2010

Software Developments Extend Capabilities in Advanced Gauges

The propagation of sound waves through air and other materials was studied as early as the nineteenth century, but the introduction of ultrasonic instruments required the electronic advances of the early twentieth century, including the development of the cathode ray tube. The idea of using ultrasonic waves to investigate the internal structure of materials was first investigated in the 1920s, and the first specific patent in the area of ultrasonic nondestructive testing dates to 1931. The first practical commercial ultrasonic test instrument, called the Reflectoscope, was patented by Prof. Floyd Firestone of the University of Michigan in 1940, and sonar development during World War II further advanced the field. In the 1950s, commercial instruments became widely available.

These early instruments were all developed primarily for ultrasonic flaw detection, although they could be used for thickness gauging as well. In the 1960s, the first smaller and more portable instruments designed for gauging began to appear, including instruments with digital thickness displays rather than oscilloscope screens. The Model 5221 introduced by Olympus' predecessor Panametrics in 1973 was the first commercial ultrasonic gauge that incorporated preset multi-mode measurement to cover a wide range of materials and thicknesses as well as a switch-set velocity calibration.

Relatively compact, battery-powered instruments optimized for a wide variety of test applications became common in the 1970s, and instruments steadily became smaller and more powerful. Waveform displays as an operator aid and internal data logging were introduced in the 1980s, and in the 1990s digital signal processing replaced analog circuitry and improved stability and repeatability. Most recently, advances in microprocessor technology have led to new levels of performance in today's sophisticated, easy-to-use miniature instruments.

1.4 Types of Equipment

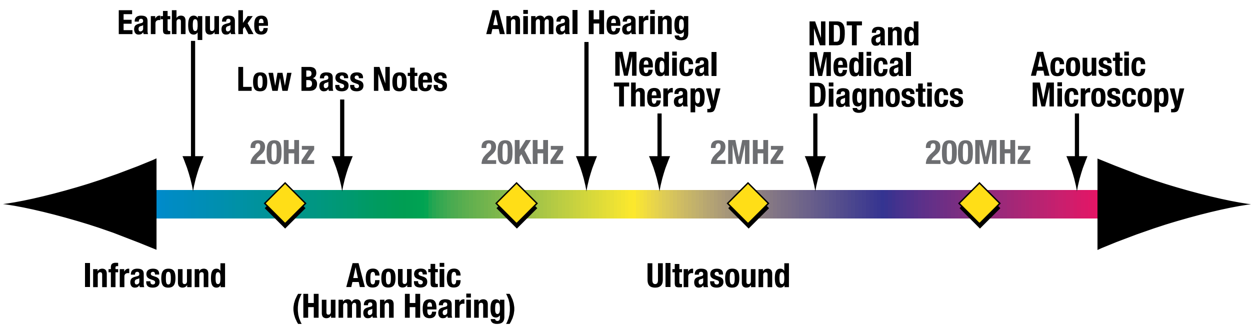
For any ultrasonic gauging application, the choice of an optimum gauge and transducer will be based on the type of test material, its thickness range, and the degree of measurement accuracy required. It is also necessary to consider part geometry, temperature, and any other special circumstances that may affect the test setup. Transducer selection is discussed in detail in Section 2 of this tutorial.

Commercial ultrasonic thickness gauges are divided into two types, corrosion gauges and precision gauges. Perhaps the single most important application for ultrasonic gauging is measuring the remaining wall thickness of metal pipes, tanks, structural parts, or pressure vessels that are subject to internal corrosion that cannot be detected from the outside. Corrosion gauges are optimized for this type of measurement, and they use specialized dual-element transducers with separate transmitter and receiver elements angled toward each other to create a V-shaped sound path in the test material. Precision gauges are generally used for all types of measurement other than corrosion survey, involving a wide variety of engineering materials and geometries. They use single element transducers.

Within those two general categories, instruments range from simple to sophisticated. The simplest gauges are small, handheld devices that are optimized for specific applications using a limited number of transducers. More sophisticated instruments incorporate waveform displays to aid the operator in test setup and interpretation, as well as more advanced signal analysis software. Data logging capability and PC compatibility are universal among the better instruments currently available on the market.

1.5 Theory of Operation

Sound waves are all around us, as mechanical vibrations carried by a medium such as air or water. Ultrasonic testing involves frequencies beyond the upper limit of human hearing, higher than 20 kHz and most commonly in the range from 500 kHz to 20 MHz, although higher and lower frequencies are sometimes used as well. The exact test frequency will be selected with respect to the specific application at hand. All ultrasonic thickness gauges work by very precisely measuring how long it takes for a sound pulse that has been generated by a probe called an ultrasonic transducer to travel through a test piece. Sound waves will reflect from boundaries between dissimilar materials, such as the air or liquid on the inside of a steel pipe wall, so this measurement can normally be made from one side in a “pulse/echo" mode.



The transducer contains a piezoelectric element, which is excited by a short electrical impulse to generate a burst of ultrasonic waves. The sound waves are coupled into the test material and travels through it until they encounter a back wall or other boundary. The reflections then travel back to the transducer, which converts the sound energy back into electrical energy. In essence, the gauge listens for the echo from the opposite side. Typically, this time interval is only a few millionths of a second. The gauge is programmed with the speed of sound in the test material, from which it can then calculate thickness using the simple mathematical relationship

$T = (V) \times (t/2)$

where

T = the thickness of the part
V = the velocity of sound in the test material
t = the measured round-trip transit time

In some cases, a zero offset is also subtracted to account for fixed delays in the instrument and sound path.

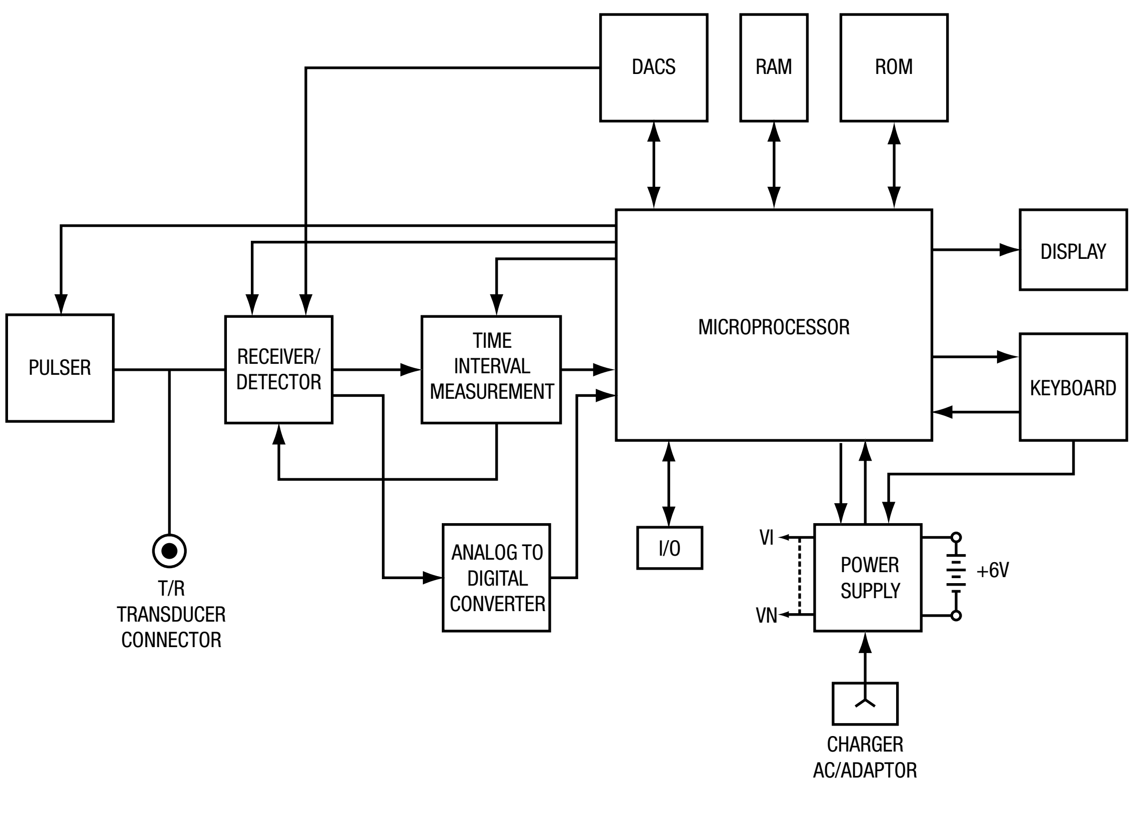
It is important to note that the velocity of sound in the test material is an essential part of this calculation. Different materials transmit sound waves at different velocities, generally faster in hard materials and slower in soft materials, and sound velocity can change significantly with temperature. Thus, it is always necessary to calibrate an ultrasonic thickness gauge to the speed of sound in the material being measured, and accuracy can be only as good as this calibration. This is normally done with a reference standard whose thickness is precisely known. In the case of high-temperature measurements, it is also necessary to remember that sound velocity changes with temperature, so for optimal accuracy, the reference standard should be at the same temperature as the test piece.

Higher frequencies have a shorter associated wavelength, permitting measurement of thinner materials. Lower frequencies with a longer wavelength will penetrate farther and are used to test very thick samples, or for materials like fiberglass and coarse-grained cast metals that transmit sound waves less efficiently. Selecting an optimal test frequency often involves balancing these requirements for resolution and penetration. In the ultrasonic frequency range, sound waves are highly directional, and while they will travel freely through typical metals, plastics, and ceramics, they will reflect from an air boundary such as an inner wall or a crack.

Sound waves in the megahertz range do not travel efficiently through air, so a drop of coupling liquid is used between the transducer and the test piece to achieve good sound transmission. Common couplants are glycerin, propylene glycol, water, oil, and gel. Only a small amount is needed, just enough to fill the extremely thin air gap that would otherwise exist between the transducer and the target.

A block diagram of a typical ultrasonic thickness gauge is shown below. The pulser, under the control of the microprocessor, provides a voltage impulse to the transducer, generating the outgoing ultrasonic wave. Echoes returned from the test piece are received by the transducer and converted back into electrical signals, which are fed into the receiver amplifier and then digitized. The microprocessor-based control and timing logic both synchronizes the pulser and selects the appropriate echoes that will be used for the time interval measurement.

If echoes are detected, the timing circuit will precisely measure a time interval in one of the modes discussed in Section 3, and then typically repeat this process several times to obtain an averaged reading. The microprocessor then uses this time interval measurement along with programmed sound velocity and zero offset values to calculate thickness. Finally, the thickness is displayed and updated at a selected rate.



2.0 Ultrasonic Transducers for Thickness Gauging

2.1 Transducer Types

All transducers that are commonly used with ultrasonic thickness gauges incorporate a vibrating ceramic element in a case, but their designs fall into four general categories.

Contact transducers: As the name implies, contact transducers are used in direct contact with the test piece. A thin, hard wearplate protects the active element from damage in normal use. Measurements with contact transducers are often the simplest to implement, and they are usually the first choice for most common thickness gauging applications other than corrosion gauging.

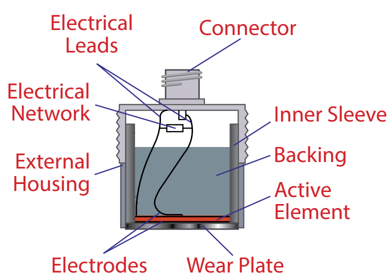
Delay line transducers: Delay line transducers incorporate a cylinder of plastic, epoxy, or fused silica known as a delay line between the active element and the test piece. A major reason for using them is for thin material measurements, where it is important to separate the excitation pulse recovery from back wall echoes. A delay line can be used as a thermal insulator, protecting the heat-sensitive transducer element from direct contact with hot test pieces, and delay lines can also be shaped or contoured to improve sound coupling into sharply curved or confined spaces.

Immersion transducers: Immersion transducers use a column or bath of water to couple sound energy into the test piece. They can be used for in-line or in-process measurement of moving product, for scanned measurements, or for optimizing sound coupling into sharp radiuses, grooves, or channels.

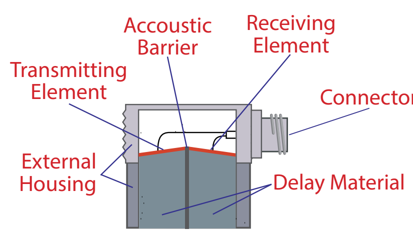
Dual element transducers: Dual element transducers, or duals, are used primarily for measurements involving rough, corroded surfaces. They incorporate separate transmitting and receiving elements mounted on a delay line at a small angle to focus sound energy a selected distance beneath the surface of a test piece. Although measurement with duals is sometimes not as accurate as with other types of transducers, they usually provide significantly better performance in corrosion survey applications.

2.2 Transducer Construction

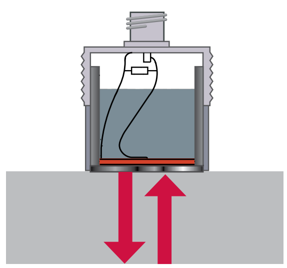
Ultrasonic transducers for thickness gauging come in a wide variety of sizes, frequencies, and case styles, but most have a common internal structure. Typically, the active element of the transducer is a thin disk, square, or rectangle of piezoelectric ceramic that converts electrical energy into mechanical 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 often referred to informally as the crystal, is protected from damage by a wearplate 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, 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 wearplate or lens.

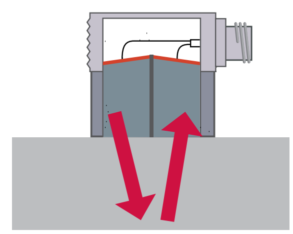


Single Element Transducer



Duel Element Transducer





2.3 Ultrasonic Beam Characteristics

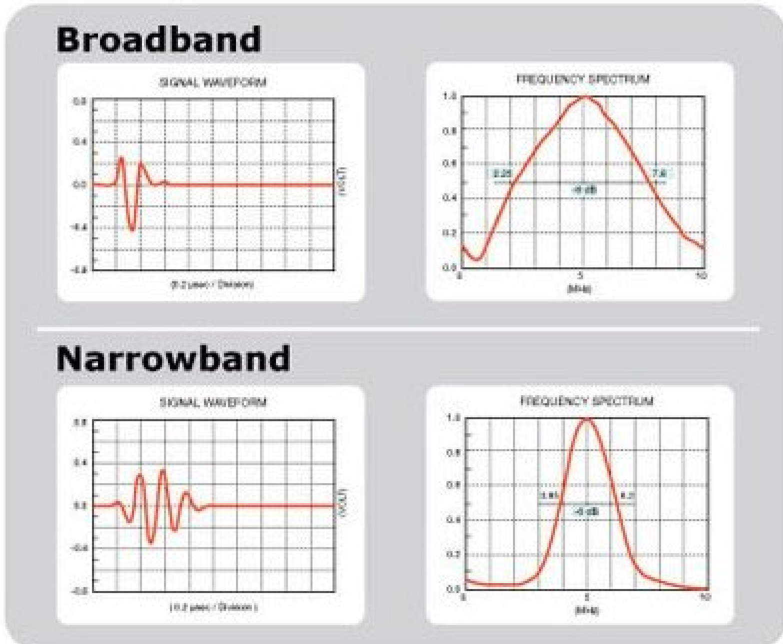
Transducers commonly used for ultrasonic gauging will have these fundamental functional properties, which affect the properties of the sound beam that they will generate in a given material:

Type: The transducer will be identified according to its design and function as a contact, delay line, or immersion type. Physical characteristics of the test material such as surface roughness, temperature, and accessibility, as well as its sound transmission properties and the range of thickness to be measured, 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. Smaller diameter transducers are often most easily coupled to the test material, while larger diameters may couple more efficiently into rough surfaces due to an averaging effect. Larger diameters are also required for design reasons as transducer frequency decreases.

Frequency: The number of wave cycles completed in one second, normally expressed in kilohertz (kHz) or megahertz (MHz). Most ultrasonic gauging 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: Typical transducers for thickness gauging do not generate sound waves at a single pure frequency, but rather over a range of frequencies centered at the nominal frequency designation. Bandwidth is the portion of the frequency response that falls within specified amplitude limits. Broad bandwidth is usually desirable in thickness gauging applications involving contact, delay line, and immersion transducers.

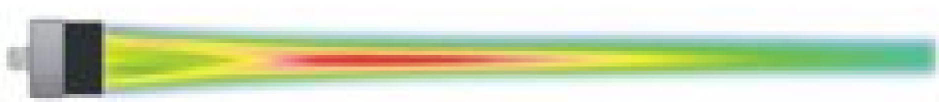


Waveform duration: The number of wave cycles generated by the transducer each time it is pulsed. A narrow bandwidth transducer has more cycles than a broader bandwidth transducer. Element diameter, backing material, electrical tuning, and transducer excitation method all impact waveform duration. A short wave duration (broadband response) is desirable in most thickness gauging applications.

Sensitivity: The relationship between the amplitude of the excitation pulse and that of the echo received from a designated target. This is a function of the energy output of the transducer.

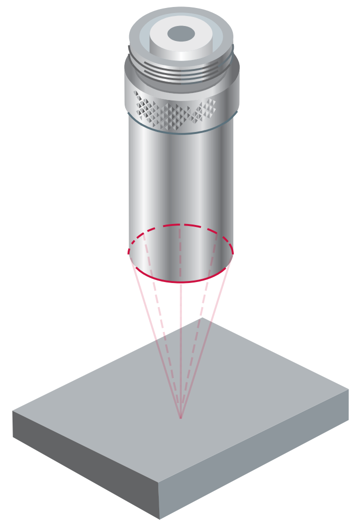
Beam profile: As a working approximation, the beam from a typical unfocused disk transducer is often thought of as a column of energy originating from the active element area that travels as a straight column for a while and then expands in diameter and eventually dissipates, like the beam from a spotlight.

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.



The exact shape of the beam in a given case is determined by transducer frequency, transducer diameter, and material sound velocity. The area of maximum energy a short distance beyond the face of the transducer marks the transition between beam components known as the near field and the far field, each of which is characterized by specific types of pressure gradients. Near field length is an important factor in ultrasonic flaw detection, since it affects the amplitude of echoes from small flaws like cracks, but it is usually not a significant factor in thickness gauging applications.

Focusing: 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 measuring small-diameter tubing or other test pieces with sharp radiuses, since it concentrates sound energy in a small area and improves echo response.



Attenuation: As it travels through a medium, the organized wave front generated by an ultrasonic transducer will begin 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. Attenuation varies with material and increases proportionally to frequency. As a general rule, hard materials like metals are less attenuating than softer materials like plastics. Attenuation ultimately limits the maximum material thickness that can be measured with a given gauge setup and transducer, since it determines the point at which an echo will be too small to detect.

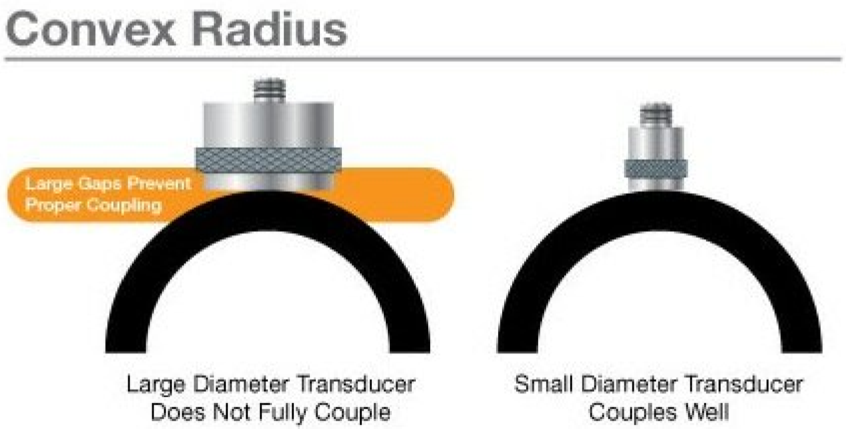
2.4 Transducer Selection

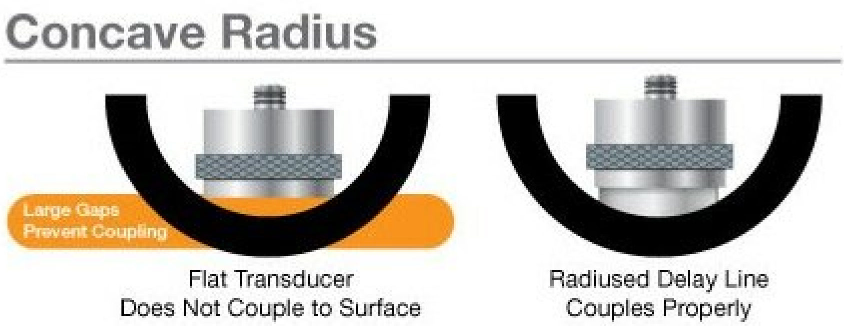
Selecting the proper transducer is an essential factor for ensuring optimal performance in any ultrasonic gauging application. It is necessary to consider the material being measured, the range of thickness that must be covered, part geometry, and part temperature. A wide variety of transducers with various acoustic characteristics have been developed to meet the needs of industrial applications. Typically, lower frequencies of 2.25 MHz and below will be used to optimize penetration when measuring thick, highly attenuating, or highly scattering materials, while higher frequencies of 5 MHz and above will be recommended to optimize resolution in thinner, non-attenuating, non-scattering materials.

Material: The type of material and the range of thickness being measured are the most important factors in selecting a gauge and transducer. Many common engineering materials, including most metals, ceramics, and glass, transmit ultrasound very efficiently and can easily be measured across a wide thickness range. Most plastics absorb ultrasonic energy more quickly and thus have a more limited maximum thickness range, but can still be measured easily in most manufacturing situations. Rubber, fiberglass, and many composites can be much more attenuating and often require high penetration gauges with pulser/receivers optimized for low frequency operation.

Thickness: Thickness ranges will also dictate the type of gauge and transducer that should be selected. In general, thin materials are measured at high frequencies and thick or attenuating materials are measured at low frequencies. Delay line transducers are often used on very thin materials, although delay line (and immersion) transducers will have a more restricted maximum measurable thickness due to potential interference from a multiple of the interface echo. In some cases involving broad thickness ranges and/or multiple materials, more than one transducer type may be required.

Geometry: As the surface curvature of a part increases, the coupling efficiency between the transducer and the test piece is reduced, so as radius of curvature increases the size of the transducer should generally be decreased. Measurement on very sharp radiuses, particularly concave curves, may require specially contoured delay line transducers or non-contact immersion transducers for proper sound coupling. Delay line and immersion transducers may also be used for measurement in grooves, cavities, and similar areas with restricted access.





Temperature: Common contact transducers can generally be used on surfaces up to approximately 125° F or 50° C. The use of most contact transducers on hotter materials can result in permanent damage due to thermal expansion effects. In such cases, delay line transducers with heat-resistant delay lines, immersion transducers, or high-temperature dual element transducers should always be used. See section 7.1 for further information on high-temperature measurements.

In general, the most reliable and repeatable results will be obtained with the highest frequency and smallest diameter transducer that will give adequate performance over the thickness range to be measured. Small-diameter transducers are more easily coupled to the test piece and permit the thinnest couplant layer at a given coupling pressure. Further, higher frequency transducers produce signals with faster rise times, thereby enhancing measurement accuracy. On the other hand, the acoustic properties or surface condition of the test material may require that transducer frequency be lowered to overcome poor coupling and/or sound attenuation or scattering within the material.

Corrosion applications are a category in themselves, normally handled with dual element transducers. Duals are typically rugged and able to withstand exposure to high temperatures and are highly sensitive to detection of pitting or other localized thinning conditions. However, they are generally not recommended for precision gauging applications because of the possibility of zero drift and timing imprecision due to the trigonometric correction required by the V-shaped sound path that they generate.

Some general recommendations for transducers that can be used for common materials and thickness ranges can be found in the Appendices Section.

3.0 Modes of Measurements

3.1 How Do Ultrasonic Thickness Gauges Work?

Whether you want to learn the basics of ultrasonic thickness gauges or are looking for a more in-depth understanding of these devices, this guide explores their technicalities, modes of measurement, and key considerations. Ultrasonic thickness gauges can be used to measure a variety of materials, so having a better understanding of how they operate can help you perform more accurate, efficient tests.

How Do Ultrasonic Gauges Measure Thickness?

Ultrasonic gauges use the physics of sound waves to measure the thickness of a test piece. They do so by analyzing the pattern of how organized mechanic vibrations travel through metals, plastics, and other industrial materials and timing how long it takes to transmit a sound pulse through the test piece until it bounces back off an inside surface or a far wall. Usually, the longer it takes, the thicker the material. These ultrasonic devices use sound energy frequencies that are far higher than those that can be heard by the human ear. Audible sound usually occurs at around 20 kHz, but ultrasonic thickness gauges can operate at up to 500 kHz or even higher.

The transducers that transmit the sound pulses contain piezoelectric elements, which are excited by short electrical impulses. This generates ultrasonic soundwaves that pass through the test piece and reflect back to the transducer. Once the sound pulse comes back, it is converted from sound energy. The gauge uses this sound energy to calculate the thickness based on the following equation:

T = (**V**) x (**t**/2)
T = the thickness of the part
V = the velocity of sound in the test material
t = the measured round-trip transit time

Modes of Measurement

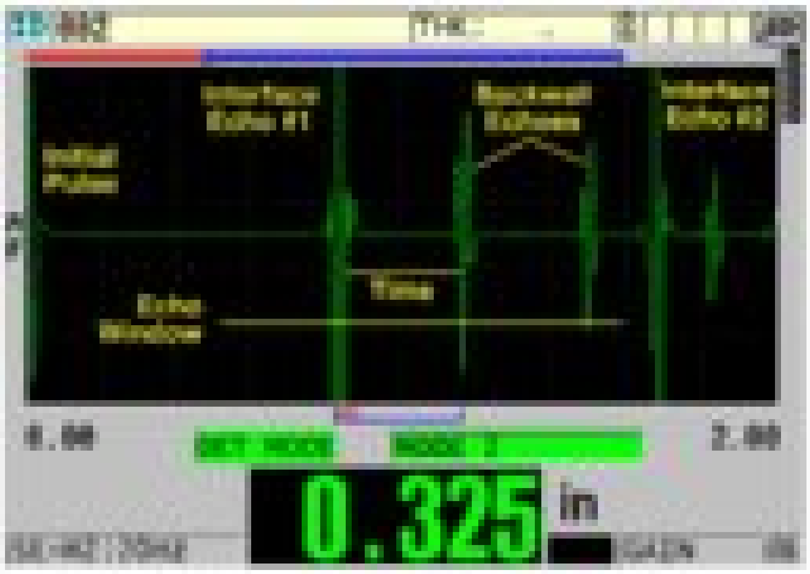
Single Element Transducers: Mode 1, Mode 2, and Mode 3

Once a sound pulse has been generated and echoes have been received, timing can be performed in a few ways. Three common methods to measure the time interval that represents the sound wave's travel through the test piece when using common contact, delay line, and immersion transducers are Mode 1, Mode 2, and Mode 3. The transducer type and application requirements usually determine which mode you choose.

Mode 1 is the most common approach. It measures the time interval between the excitation pulse that generates the sound wave and the first returning echo and then subtracts a small zero offset value that compensates for fixed instrument, cable, and transducer wear plate delays.

Mode 1 is the normal measurement mode when testing with contact transducers. Its key advantage is that it typically offers the greatest maximum thickness capability. Since only a single back wall echo is required, it also has the best penetration capability in challenging materials like castings, low density plastics, and rubber. The disadvantages of Mode 1 are that the minimum measurable thickness will be higher than in other modes, and accuracy can be slightly lower due to coupling variations. Also, the contact transducers associated with Mode 1 can be used only on materials with a surface temperature below 50° C or 125° F, so high-temperature measurement is impossible.

Mode 2 involves measuring the time interval between an interface echo returned from the near surface of the test piece and the first back wall echo, which represents one round trip in the test piece. This mode normally requires delay line or immersion transducers.



Mode 2 is often used to:

- Optimize near-surface resolution in plastics and composites
- Perform high-temperature measurements with high-temperature delay line transducers
- Take measurements on sharp radiuses using focused immersion transducers and focused or radiused delay line transducers
- Perform in-line measurement of moving material using immersion transducers

The main disadvantage of Mode 2 measurement is that maximum thickness is limited by delay line length.

Mode 3 involves measuring the time interval between two successive back wall echoes, representing one round trip in the test piece using delay line or immersion transducers.

Mode 3 typically offers the highest measurement accuracy and best minimum thickness resolution, although the maximum thickness will be limited. This mode requires two or more clean multiple back wall echoes, which typically limits its use to materials of relatively low attenuation and high acoustic impedance like fine-grained metals, ceramics, and glass. Measurements can be made at high temperatures with appropriate high-temperature delay lines. Mode 3 also offers the advantage of removing thin nonmetallic coatings like paint from the thickness measurement of coated metals.

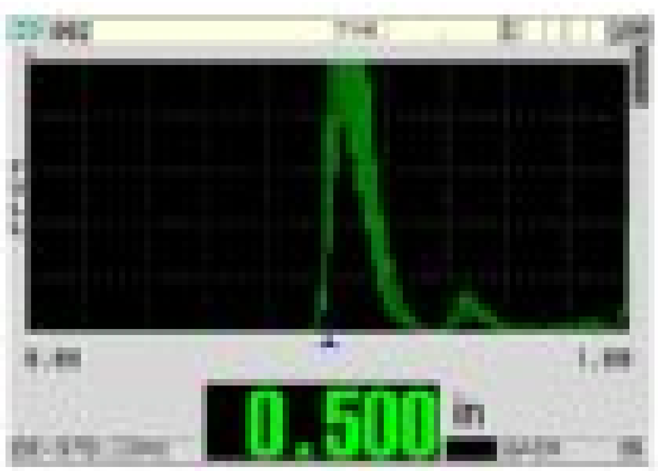
Dual Element Transducers

Dual element transducers incorporate separate transmitting and receiving elements mounted on delay lines that serve both as waveguides to aim the sound beam in a V-shaped path and as thermal insulators to protect the active element during high-temperature measurements. Echo timing is often performed in Mode 1 with a large zero offset to subtract the pulse transit time through the delay lines, as well as a trigonometric correction to compensate for the V-shaped sound path in the test material.

Ultrasonic Thickness Gauge Measurement Considerations

When measuring with ultrasonic thickness gauges, you must consider many external influences to help ensure accuracy and safety. For more information, head to the following pages to learn about factors that affect ultrasonic testing and inspection conditions:

- High-Temperature Measurements
- Material-Related Factors



4.0 Calibrating an Ultrasonic Thickness Gauge

4.1 What Is Ultrasonic Thickness Gauge Calibration?

An ultrasonic gauge reads the thickness of a test piece by very precisely timing echoes. To turn these time measurements into thickness measurements, the gauge must be programmed with the speed of sound in the test material and any necessary zero offset required by the instrument, transducer type, or echo shape. This process is commonly called gauge calibration. The accuracy of any ultrasonic measurement is only as good as the accuracy and care taken during calibration. Incorrect calibration will result in inaccurate thickness readings. The good news is that calibration is usually a simple process.

Many different calibrations for various materials and transducers can be stored in the gauge and quickly recalled. It is important to remember to perform a new calibration or recall an appropriately programmed calibration when the test material or transducer is changed, or if the temperature of the test material changes significantly. Also, we recommend performing periodic checks with samples of known thickness to verify that the gauge is operating properly, especially in critical applications.

Ultrasonic Thickness Gauge Calibration Chart

When using ultrasonic thickness gauges, the speed of the sound energy used to take thickness measurements depends on the test material. View the table below to see the sound velocity of different materials:

Material	Velocity (m/s)
Lead	1160–1320
Aluminum	3040–6420
Concrete	3200–3700
Wood	3300–5000
Copper	3560–3900
Brick	3600–4200
Iron	3850–5130
Glass	3950–5000
Steel	4880–5050

You can use this information to establish a pulse transit time to provide and maintain accurate thickness values.

4.2 Velocity and Zero Calibration

In velocity calibration, the gauge 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 gauge 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. Major factors that are included together in the zero value are electronic switching delays in the gauge, cable delays, transducer delays, and couplant delays. In the case of contact transducers, the transducer delay comprises the amount of time it takes for sound energy to exit the transducer through its protective wearplate. In the case of dual element transducers, the transducer delay is the amount of time it takes for sound energy to pass through the transducer's delay lines or standoff. (In Mode 2 and Mode 3 measurements, where timing is performed from an interface echo representing the point at which sound energy enters the test piece, the transducer component of the zero offset value is generally zero.)

The recommended procedure for velocity and zero calibration is a two-point calibration, which requires two samples of the test material of different thicknesses within the thickness range to be measured and whose thicknesses are precisely known. These do not have to be commercial test blocks, as long as their thickness is known. It is much more important that the material used for calibration be exactly the same as the material being measured and ideally have the same surface finish as well. The two blocks should have a 2:1 or greater thickness ratio, with a 5:1 or greater ratio being optimum.

A common calibration sequence is as follows:

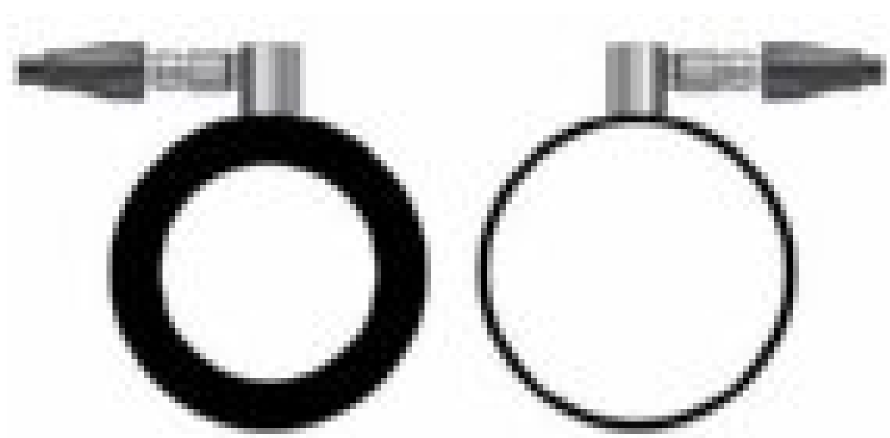
1. Couple the transducer to the thick reference sample.
2. Using the keypad, enter the "calibrate velocity" command.
3. When the thickness reading is stable, press ENTER.
4. Using the keypad, adjust the displayed value to correspond to the actual thickness of the thick reference sample.
5. Couple the transducer to the thin reference sample.
6. Using the keypad, enter the "calibrate zero" command.
7. When the thickness reading is stable, press ENTER.
8. Using the keypad, adjust the displayed value to correspond to the actual thickness of the thin reference sample.
9. Press the MEASURE key to complete the process.

Using the four available data points, the two entered thickness values plus the measured transit time associated with each, the gauge 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.

Two Point Calibration

Calibration on actual sample having:

- Same surface conditions
- Same geometry
- Same material



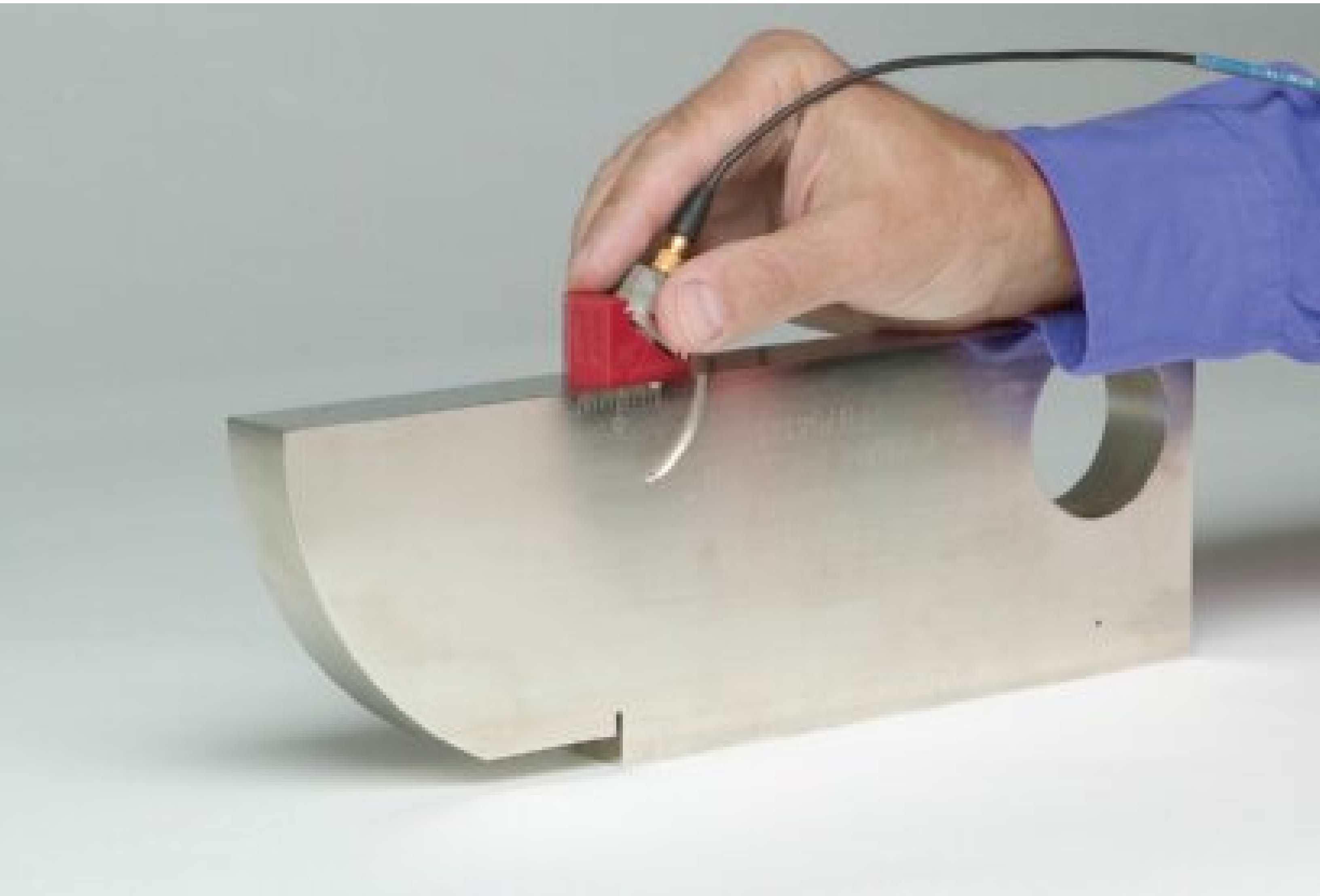
Enter Max Sample Thickness   Enter Min Sample Thickness

4.3 Calibration Certification


OLYMPUS

Calibration certification is the process of documenting the measurement accuracy of a thickness gauge under specific test conditions. Manufacturer's calibration certification is usually performed with thickness reference standards whose thickness is traceable to the National Institute of Standards and Technology (NIST). Measurement accuracy under documented test conditions is typically compared with the manufacturer's established tolerance for a given gauge, transducer, gauge setup, and material.

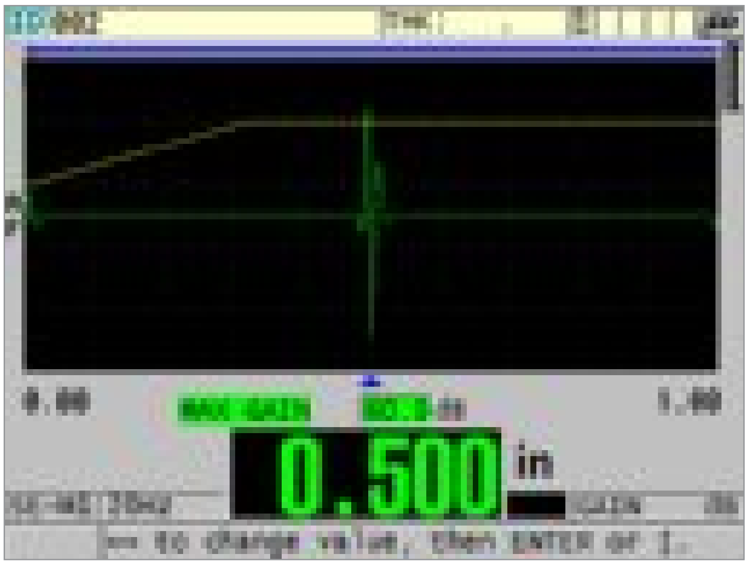
It is important to note that ultrasonic gauges must always be certified as part of a system that includes the transducer as well as the gauge setup, since the measurement accuracy of any ultrasonic gauge is dependent on the performance and proper usage of both the gauge and transducer. A calibration certificate is only a record of gauge performance under the stated conditions, using a specific transducer. System performance with other transducers may vary, especially transducers that have been subject to wear or overheating. Additionally, use of the gauge on materials other than the reference standards used for calibration certification will require a new velocity recalibration. If that process is performed incorrectly, inaccuracies will result. It is the responsibility of the user to verify measurement accuracy to whatever level they require for a given test. This is usually easy to do by simply checking readings with proper reference standards of known thickness.



5.0 Gauge Setup Considerations

5.1 Overview of Thickness Gauge Setup

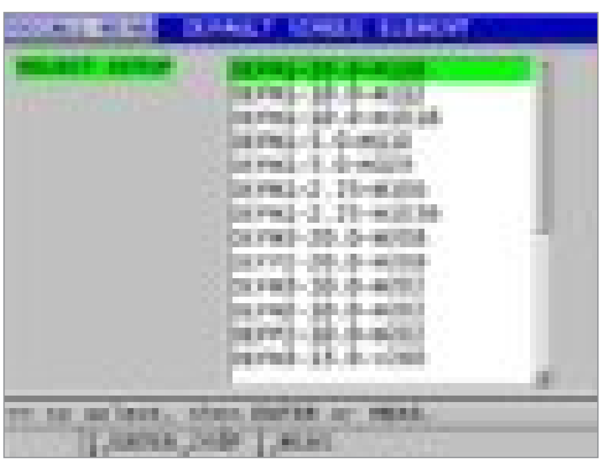
In addition to the velocity and zero calibrations discussed in the previous section, ultrasonic thickness gauges require a series of hardware and software settings that affect the shape and size of the outgoing sound pulse and how received echoes are processed and timed. These settings will change depending on transducer selection and the type of material and thickness range being measured. In some cases these parameters are set automatically by means of probe recognition software, especially with corrosion gauges. In many other cases an operator can simply recall a pre-programmed gauge setup that includes the appropriate settings for a particular application. However, advanced gauges also enable the user to adjust setup parameters and create optimized setups as required for applications not otherwise covered.

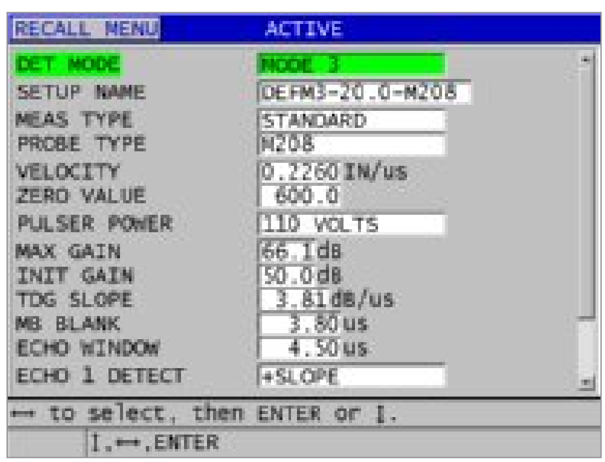


Custom setups are typically used when the measurement requirements of a particular application are not optimally met by one of the standard setups available in a gauge.

Setup adjustments of this type should be made only by a qualified technician who is familiar with the basic theory of ultrasonic gauging and the interpretation of ultrasonic waveforms. Many of these adjustments are interactive, and all of them have an effect on measurement range and/or measurement accuracy. In most cases, adjustments should not be attempted without monitoring waveforms via built-in waveform displays or auxiliary programs. Additionally, when establishing a custom setup for a specific application, it is essential to verify performance on reference standards representing the material(s) and thickness range to be measured before taking data.

The next section discusses some adjustable setup parameters that are commonly found in advanced ultrasonic gauges. Note that not all of these adjustments will necessarily be available in a given model.





5.2 Typical Thickness Gauge Adjustments

Pulser/Receiver Settings

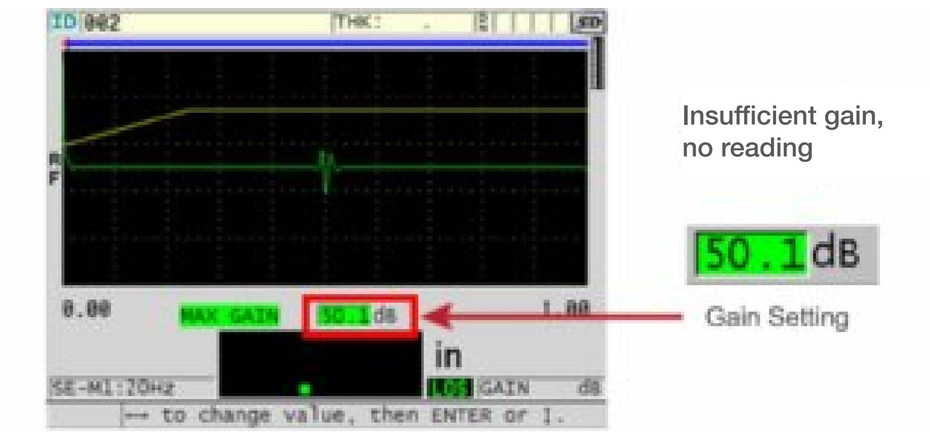
The parameters in this section affect the excitation pulse sent to the transducer and the processing of returned echoes.

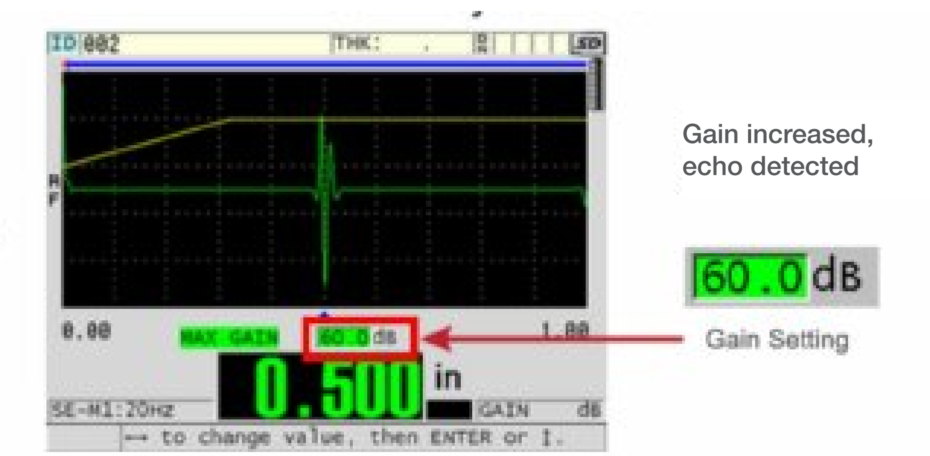
Pulser energy: Permits selection of higher or lower excitation pulse energy. Higher energy optimizes penetration, while lower energy optimizes near-surface resolution.

Pulser frequency: Advanced gauges utilize tuned pulsers that vary the frequency of the excitation pulse for optimum transducer performance.

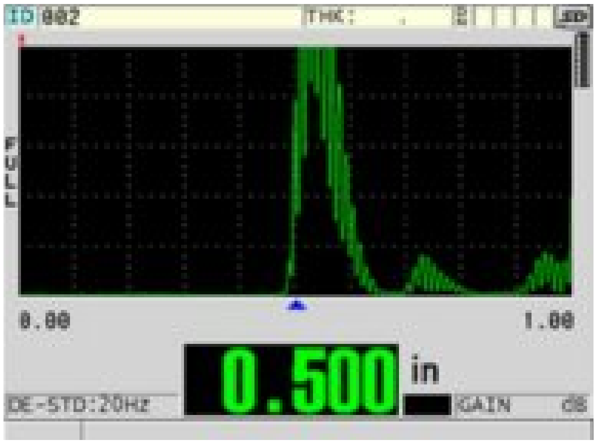
Receiver gain: Gauges will typically operate with a default level of amplification applied to received echoes. Many gauges permit user adjustment of gain to optimize response in applications involving very thin materials, thick or highly attenuating materials, or scattering materials. Automatic gain control is often employed to adjust echo height to an optimum level for detection and avoid saturated signals. Advanced gauges will also incorporate time varied gain, which allows use of lower gain for thin measurements and higher gain for thick measurements, further optimizing echo detection over a broad thickness range.

Gain Adjustments

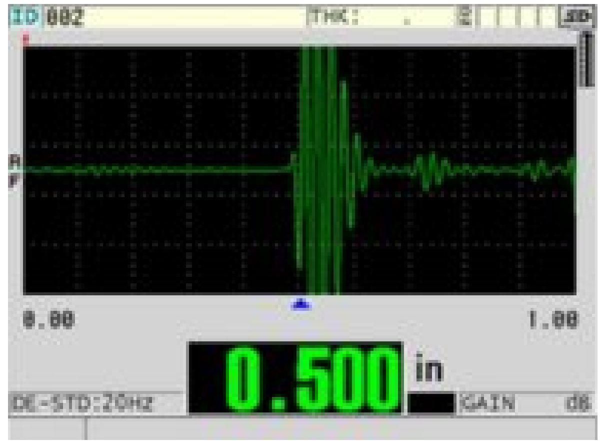




Rectification: Many waveform display gauges permit display of received echoes as either an RF signal or a rectified signal (full wave or half wave). This can be an aid to echo interpretation in challenging applications.



Full wave rectification



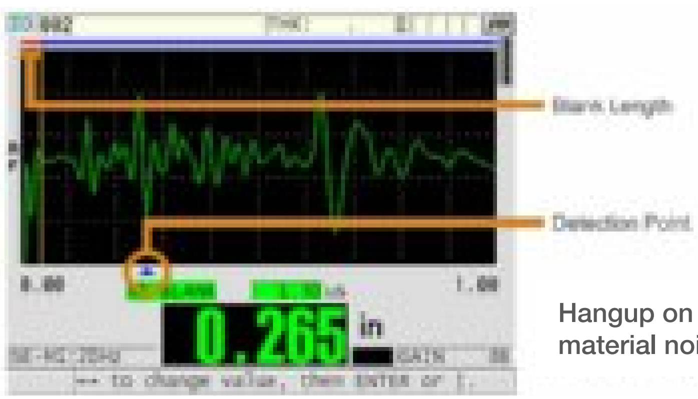
RF waveform

Detection and Timing Settings

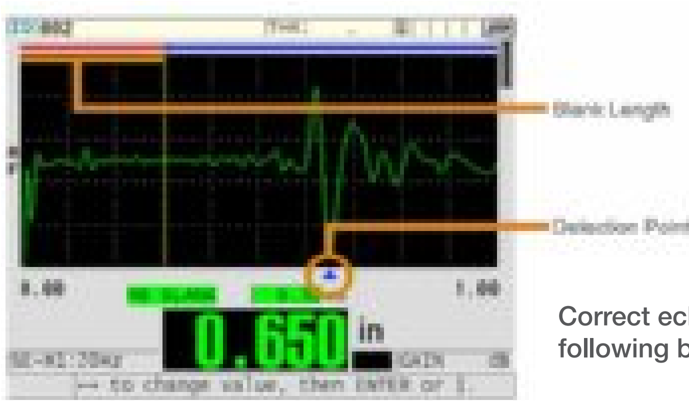
The parameters in this section determine which received echoes in a wave train will be detected and timed as the basis for thickness measurement.

Measurement mode: Most gauges will automatically select one of the measurement modes described in Section 3 as part of any default setup, however advanced users may wish to change the measurement mode to optimize performance or choose the mode when beginning a custom setup.

Echo Blanking Adjustments



Hangup on material noise



Correct echo detected following blanking adjustment

Echo polarity: Permits section of the optimum lobe of unrectified echoes in situations where material acoustic impedance relationships cause inversions.

6.0 Measurements Through Coatings

Paint, epoxy, and similar protective coatings on steel often present a potential issue in corrosion survey applications. Because the sound velocity of nonmetallic coatings is usually about half that of steel, a coating can add an error of double its actual thickness to a measurement. In this section, we will discuss the different measurement techniques Olympus ultrasonic thickness gauges use to measure the thickness of coatings.

Why Is It Important to Accurately Measure Coatings?

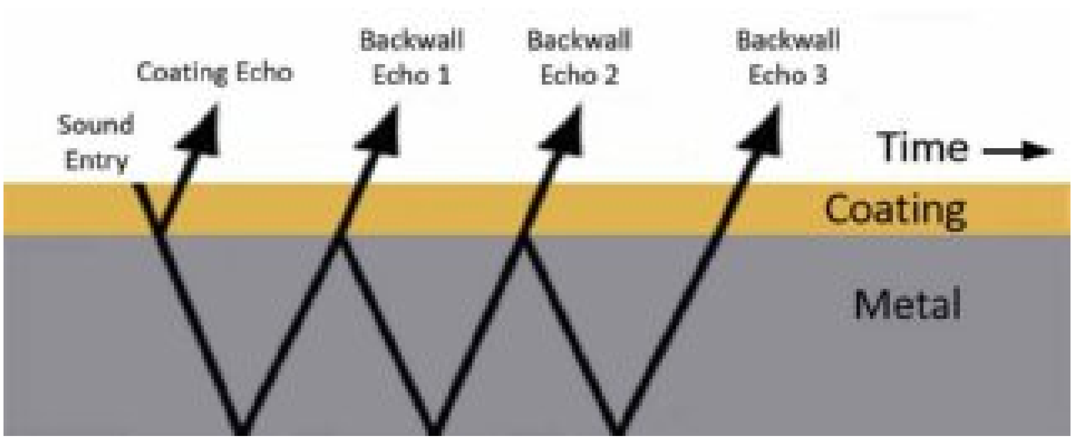
Coating thickness has a significant effect on product quality, process control, and cost control. Two factors help ensure a coating performs its intended function: the quality of the paint and the thickness of the coating. Accurately measuring a coating can guarantee that requirements are met across a range of industries. Ultrasonic gauges are nondestructive and can accurately take thickness measurements of coatings that require access on only one side of a material's surface.

Ultrasonic Coating Thickness Measurement Techniques

Two techniques to measure the thickness of coated pipes and parts are echo-to-echo and THRU-COAT™ measurement. Each technique has strengths and weaknesses:

Echo-to-Echo Measurement

The echo-to-echo measurement technique, available on the 38DL PLUS™ and 45MG (optional) thickness gauges, enables you to measure the remaining wall thickness of pipes or other metal structures while removing the coating from the measurement. This technique times the interval between two successive back wall echoes to provide an accurate representation of the metal material's thickness without the coating (as multiple back wall echoes can exist in metal but not commonly in coatings).



The advantages of using the echo-to-echo technique include:

- Works with a variety of common transducers
- Often works through rough-surfaced coatings
- Can be performed at high temperatures up to approximately 500 °C (930 °F) with the appropriate transducers

The limitations of the echo-to-echo technique include:

- Requires multiple back wall echoes, which might not exist in severely corroded metals
- Thickness range is sometimes more limited than with a THRU-COAT measurement

THRU-COAT™ Measurement:

The THRU-COAT measurement technique enables separate measurement of thin nonmetallic coatings like paint over metal and the metal thickness. This technique uses patented software to identify the time interval represented by one round trip in the coating. By subtracting this time interval from the total measurement, the metal substrate's thickness can be calculated. THRU-COAT measurement may not work properly if the coating's thickness is below 0.125 mm (0.005 in.) or if the external coated surface is rough or irregular. For more details on THRU-COAT measurement, see our guide on thickness gauge modes of measurement.

The advantages of using THRU-COAT technology over the echo-to-echo technique include:

- Works over a wide range of metal thicknesses, typically from 1 mm (0.04 in.) to greater than 50 mm (2 in.) in steel
- Requires only one back wall echo
- May measure minimum remaining metal thickness more accurately when there is pitting in the metal

Some of the disadvantages of using THRU-COAT technology are:

- Coating must be nonmetallic and at least 0.125 mm (0.005 in.) thick
- Coating surface must be relatively smooth
- Requires you to use one of two special transducers
- Can only be used on surfaces with a maximum temperature of 50 °C (125 °F)

For more information on how to use Olympus ultrasonic thickness gauges to measure remaining wall thickness through coatings, view the product video tutorials in our Resource Center.

7.0 Factors Affecting Measurement

7.1 Factors That Can Impact Testing

Quality ultrasonic thickness gauges can offer highly accurate testing on metals, plastics, and other materials. However, several factors related to the test material, equipment, part geometry, and user skill and care can affect the degree of accuracy achieved in an application. Read on to learn factors that can impact ultrasonic testing results.

Material-Related Factors

The physical properties of the test material is one factor that affects an ultrasonic thickness gauge's measurement range and accuracy. This includes both acoustic and geometrical factors.

1. Acoustic Properties of the Test Material

Several conditions found in some engineering materials can limit the accuracy and range of ultrasonic thickness measurements:

- **Sound scattering:** In cast stainless steel, cast iron, fiberglass, and composite materials, sound energy will scatter from individual grain boundaries in castings or boundaries between fibers and matrix in the fiberglass or composite. Porosity in any material can have the same effect. Make sure to adjust the gauge sensitivity to prevent the detection of these spurious scatter echoes. This compensation can limit the gauge's ability to detect a valid return echo from the back wall of the material, restricting the measurement range.
- **Sound attenuation or absorption:** In many polymers like low density plastics and in most types of rubber, sound energy is attenuated very rapidly at the frequencies used for ultrasonic gauging. This attenuation typically increases with temperature. The maximum thickness that can be measured in these materials is often limited by attenuation.
- **Velocity variations:** An ultrasonic thickness measurement is accurate only to the degree that the material sound velocity is consistent with the gauge's velocity calibration. Some materials exhibit major variations in sound velocity from point to point. This happens in some cast metals due to the changes in grain structure that result from varied cooling rates and the anisotropy of sound velocity with grain structure. Fiberglass can show localized velocity variations due to changes in the resin/fiber ratio. Many plastics and rubbers show a rapid change in sound velocity with temperature, requiring that operators perform the velocity calibration at the same temperature as the measurement.
- **Phase reversal or phase distortion:** The phase or polarity of a returning echo is determined by the relative acoustic impedance (density × velocity) of the boundary materials. Ultrasonic gauges assume the customary situation where the test piece is backed by air or a liquid, both of which have a lower acoustic impedance than metals, ceramics, or plastics. However, in some specialized cases, such as measurement of glass or plastic liners over metal, or copper cladding over steel, this impedance relationship is reversed and the echo appears phase reversed. To maintain accuracy in this situation, make sure to change the appropriate echo detection polarity. An even more complex situation can occur in anisotropic or in homogeneous materials, such as coarse-grain metal castings or certain composites, where material conditions result in multiple sound paths in the beam area. In these cases, phase distortion can create an echo that is neither positive nor negative. Carefully experiment with reference standards in these cases to determine the effects on measurement accuracy.

2. Physical Properties of the Test Material

The size, shape, and surface finish of the test piece must also be considered to establish the limits of measurement range and accuracy.

- **Surface roughness of the test piece:** The best measurement accuracy is obtained when both the front and back surfaces of the test piece are smooth. If the contact surface is rough, then the minimum thickness that can be measured will be increased because of sound reverberating in the increased thickness of the couplant layer. Inefficient coupling may reduce the echo amplitude. Also, if either the top or bottom surface of the test piece is rough, it can cause distortion in the returning echo due to the slightly different multiple sound paths seen by the transducer, resulting in measurement inaccuracies.

  For corrosion measurements, loose or flaking scale, rust, corrosion, or dirt on the outside surface of a test piece will interfere with the coupling of sound energy from the transducer into the test material. For this reason, clean any loose debris from the sample with a wire brush or file before measuring. Generally, performing corrosion measurements through thin layers of rust is possible as long as the rust is smooth and well bonded to the metal below. Keep in mind that some very roughcast or corroded surfaces might need to be filed or sanded smooth to ensure proper sound coupling. You may also need to remove paint if it is flaking off the metal.

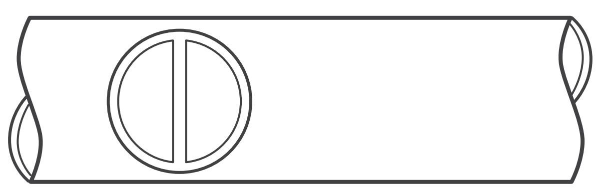
- **Curvature of the test piece:** A related issue is the transducer alignment with the test piece. When measuring on curved surfaces, it is important to place the transducer around the centerline of the part and hold it as steadily as possible on the surface. A spring-loaded V-block holder can be helpful for maintaining this alignment. In general, as the radius of curvature decreases, the size of the transducer should be reduced, and transducer alignment becomes progressively more critical. For very small radii, an immersion approach with a focused transducer is required. In some cases, it helps to use a waveform display as an aid to maintain the best alignment. Also, on curved surfaces it is important to use only enough couplant to obtain a reading. Excess couplant will form a fillet between the transducer and the test surface where sound will reverberate and might create spurious signals that can trigger false readings.
- **Taper or eccentricity:** If the contact surface and back surfaces of the test piece are tapered, eccentric, or otherwise angled or misaligned with each other, the return echo will be reduced in amplitude and might be distorted due to the variation in sound path across the width of the beam, reducing the measurement accuracy. Typically, the measured thickness will represent an approximate integrated average of the changing thicknesses in the beam diameter. In cases of significant misalignment, measurement is impossible because the reflected beam will form a V-path away from the transducer and cannot be received. This effect becomes greater as the material thickness increases.

Operator-Related Factors

The physical properties of the test material is one factor that affects an ultrasonic thickness gauge's measurement range and accuracy. This includes both acoustic and geometrical factors.

- **Calibration:** The accuracy of any ultrasonic measurement is only as good as the accuracy and care taken during calibration. Make sure to perform the velocity and zero calibrations described in Section 4 when the test material or transducer is changed. We also recommend periodic checks with samples of known thickness to verify that the gauge is operating properly.
- **Beam alignment:** Always hold the transducer flat when testing on flat surfaces and normal to the radius of curvature when testing on curved surfaces. When testing on curved surfaces, always center the transducer on the curve. Misalignment will cause echo distortion, which will negatively affect the accuracy.
- **Coupling technique:** In Mode 1 measurements with contact transducers, the couplant layer thickness is part of the measurement and is compensated by a portion of the zero offset. To achieve maximum accuracy, the coupling technique must be consistent. For consistent measurements, use only enough couplant to achieve a stable reading and apply the transducer with uniform pressure. Practice will show the degree of moderate to firm pressure that produces repeatable readings. Also, never scrape or drag transducers across rough surfaces. In general, smaller-diameter transducers require less coupling force to squeeze out the excess couplant than larger diameter transducers. In all modes, tilting the transducer distorts echoes and causes inaccurate readings.

For corrosion gauging on small-diameter pipes and tubes, hold the transducer so that the sound barrier material visible on the probe face is aligned perpendicular to the center axis of the pipe, as shown below.



Equipment-Related Factors

While instrument design factors like digital sampling rate will set the limits of range and accuracy for an ultrasonic gauge, the range and accuracy in an application is ultimately determined by the combination of gauge, transducer, and setup, as well as material-related factors. For information on the typical materials and thickness ranges that can be measured with ultrasonic gauges using specific transducers and appropriate instrument setups, visit Section 9, Appendices—Transducer Range Charts.

Note that precision gauges using single element transducers typically have higher inherent accuracy than corrosion gauges using dual element transducers.

8.0 Special Conditions

8.1 How to Use Ultrasonic Thickness Gauges in Special Conditions

Taking measurements in special conditions like elevated temperatures or underwater bring up extra considerations for ultrasonic testing. If you plan to use an ultrasonic thickness gauge in any of the following conditions, please follow these recommendations to help ensure both safety and accurate results.

Ultrasonic Testing in High Temperatures

Measuring at elevated temperatures (higher than approximately 125 °F or 50 °C) requires careful planning. Many dual element transducers used in corrosion applications can withstand high temperatures, in some cases up to 930 °F or 500 °C in brief contact. However, standard contact transducers will get damaged or destroyed when exposed to temperatures higher than approximately 125 °F or 50 °C because of the varying thermal expansion coefficients of the materials used to construct them, which will cause disbonding at elevated temperatures. Never use contact transducers on a surface that is too hot to comfortably touch with bare fingers. Also, always perform high-temperature measurements with single element transducers in Mode 2 or Mode 3 with either a delay line transducer (using an appropriate high-temperature delay line) or an immersion transducer. Reach out to Olympus for more information on specific transducer selection.

Sound velocity in all materials changes with temperature, normally increasing as the material gets colder and decreasing as it gets hotter, with abrupt changes at freezing or melting points. This effect is much greater in plastics and rubber than in metals or ceramics. For maximum accuracy, calibrate the gauge sound velocity setting at the same temperature to perform measurements. Note that measuring hot materials with a gauge set to room temperature sound velocity will often lead to significant error. Finally, at temperatures greater than approximately 200 °F or 100 °C, we recommend using special high-temperature couplants.

In-Line Measurements Using Ultrasonic Thickness Gauges

In-line or in-process ultrasonic thickness gauging enables continuous measurement of products like extruded plastic pipe and tubing, electrical cable jacket, and sheet metal while the product is moving. Multichannel instruments can measure at many different locations around the circumference of a tubular product or across the width of a sheet. In-line measurement is usually performed with immersion transducers that couple sound energy through a water bath or water column to avoid the need for direct contact with the product. In the case of extruded pipe, tubing, and cable jacket, measurements can often be made within existing cooling tanks by using the cooling water as a couplant. Some affixing is needed to hold the transducer(s) in proper alignment with the test material.

Ultrasonic Testing with Long Transducer Cables

Ultrasonic gauges are most often used with transducer cables approximately 1 meter or 3 feet in length. Generally, using very long cables is not recommended unless required by test conditions. When cable length exceeds about 3 meters or 10 feet at common test frequencies, cable effects should be considered since negative effects can occur. The maximum length of cable that can be used in a specific case will depend on the transducer type and minimum thickness to be measured. Note that dual element transducers can be used with much longer cables than single element transducers, potentially as long as 100 meters or 300 feet with an appropriate instrument setup. Pay particular attention to the problems of electrically matching the transducer to the cable, accounting for attenuation of the signal in the cable, and compensating for pulse transit time through the cable.

Ultrasonic Testing Underwater

Some corrosion survey applications involve situations such as measuring the thickness of support pilings or boat hulls submerged in water. While most standard contact, delay line, and dual element transducers can be briefly immersed in shallow water without problems, long-term submersion or deep submersion (deeper than about 2 meters or 6 feet) will eventually cause failure due to corrosion and water intrusion, especially in saltwater. For a deep-water marine application, water-resistant dual element transducers that are sealed against water intrusion under high pressure are normally used. As suggested above, these transducer types are available to use at depths up to approximately 100 meters or 300 feet.

There are certain considerations to take when measuring through coatings such as paint epoxy or other protective surfaces. For more information, see our coating thickness gauge section.

9.0 Typical Ultrasonic Gauging Applications

9.1 Precision Ultrasonic Gauging—Metals

Ultrasonic thickness gauges can be used to measure a wide variety of forged, rolled, machined, cast, or extruded metal products over a thickness range from about 0.2 mm (0.008 in.) up to 500 mm (20 in.) depending on the grain structure.

What Metals Can Be Measured Using Ultrasonic Gauges?

Some common examples of metals that can be measured are listed below.

Pipes and tanks: There is corrosion measurement involving metal pipes and tanks, but precision thickness measurement during the manufacturing process is also possible.

Sheets and coils: Metal sheet and coil stock can normally be measured to very high accuracy at any point where the operator has access to one side of the material. Ultrasonic gauging is especially useful for wide products that are difficult to measure with mechanical gauges except at the edges.

Automotive sheet metal: The complex shape and large size of many automotive sheet metal fabrications can make mechanical measurement challenging, but ultrasonic gauging can be performed at any point where there is access to one side, including reduction rate measurement at bends.

Small-diameter tubing: Wall thickness and concentricity of precision metal tubing as small as 2 mm or 0.080 in. in diameter can be measured using focused transducers.

Gun drilling: Drill drift during gun drilling operations can result in holes whose position varies with depth. An ultrasonic gauge can locate and measure the depth of holes from the outside surface at any point along the length of a part.

Castings: Wall thickness of hollow ferrous and nonferrous castings can be measured ultrasonically, even those with complex shapes like engine blocks. Ultrasonic gauges can also be used to check nodularity in cast iron.

Turbine blades: The wall thickness of hollow turbine blades for aircraft engines and similar critical applications can be measured with small focused transducers, both to detect core shift during manufacturing and to gauge wear in service.

Machined parts: During machining operations, sometimes inspectors need to check the wall thickness of parts to ensure that they are within specification. Ultrasonic gauges are helpful tools for this application when the inside surface of the part is difficult or impossible to reach.

For more information on precision ultrasonic gauging of other materials, see our guide on using ultrasonic thickness gauges to measure plastics or glass and ceramics.

9.2 Precision Ultrasonic Gauging—Corrosion

Ultrasonic thickness gauges can be used to measure a wide variety of forged, rolled, machined, cast, or extruded metal products over a thickness range from about 0.2 mm (0.008 in.) up to 500 mm (20 in.) depending on the grain structure.

Corrosion Surveys

Just about anything made of common structural metals is subject to corrosion. An important challenge in many industries is measuring remaining wall thickness in pipes, tubes, or tanks that may be corroded on the inside surface. This corrosion is often undetectable by visual inspection without cutting or disassembling the pipe or tank. Ultrasonic testing is a widely accepted nondestructive method to perform this inspection, and ultrasonic testing of corroded metal is usually done with dual element transducers and dedicated corrosion gauges.

Why Is It Important to Inspect Metals for Corrosion?

Structural steel beams, particularly bridge supports and steel pilings, are also subject to corrosion that reduces the original thickness of the metal. If undetected over time, corrosion will weaken walls and can cause dangerous structural failures. Both safety and economic considerations require that metal pipes, tanks, or structures that are susceptible to corrosion are inspected regularly. Ultrasonic thickness gauges enable you to accurately detect potential internal corrosion without damaging the metal and while accessing one side of the surface.

How Do Ultrasonic Thickness Gauges Detect Corrosion?

All gauges designed for corrosion applications will measure the round-trip transit time interval to the first back wall echo. Advanced instruments can also measure the interval between successive multiple echoes. They use signal processing techniques that are optimized for detecting the minimum remaining thickness in a rough, corroded test piece. This allows these gauges to calculate the specific thickness of corrosion, without being affected by the metal or its coating.

The irregular surfaces that are frequently encountered in corrosion applications give dual element transducers an advantage over single element transducers. Dual element transducers incorporate separate transmitting and receiving elements, mounted on delay lines that are usually cut at an angle to the horizontal plane (the roof angle), so that the transmitting and receiving beam paths cross beneath the surface of the test piece. This crossed-beam design of duals provides a pseudo-focusing effect that optimizes the measurement of minimum wall thickness in corrosion applications.

Duals will be more sensitive than single element transducers to echoes from the base of pits that represent the minimum remaining wall thickness. Also, duals are often more effective on rough outside surfaces. Couplant trapped in pockets on rough sound entry surfaces can produce long, ringing surface echoes that interfere with the thin material resolution of single element transducers. With a dual, the receiver element is unlikely to pick up this false echo. Finally, most duals can make high-temperature measurements that would damage single element contact transducers.

Olympus has ultrasonic thickness gauges designed to perform detailed, accurate corrosion inspections. To learn more about how ultrasonic thickness gauges detect corrosion in metals, see our guide on how thickness gauges work.

9.3 Precision Ultrasonic Gauging—Plastics

As the use of nonmetallic engineering materials in manufacturing has increased, so has the need to measure their wall thickness for quality control. All common plastics, fiberglass, and composites can be measured ultrasonically, with access to only one side of a material required. Precision ultrasonic thickness gauges can help manufacturers ensure industry standards for quality and safety.

What Plastics Can Be Measured Using Ultrasonic Gauges?

Some common examples include:

Bottles and containers: Manufacturers of blow-molded and roto-molded bottles and containers need to check wall thickness, which is usually inaccessible to micrometers. Ultrasonic gauging can measure without needing to cut the bottles or containers.

Plastic pipe: Both in-line and off-line measurement of plastic pipe wall thickness can be performed to ensure concentricity.

Plastic tubing: Small tubing with diameters as small as 2 mm or 0.080 in., including catheters and other including medical tubing, can be measured with focused transducers.

Cable jacket and wire insulation: Thickness of plastic insulation on both large and small electrical and fiber optic cable can be measured to help ensure concentricity and compliance with minimum thickness specifications.

Plastic preforms: Both structural plastic and barrier layers can be measured in the preform stage to help ensure proper thickness in the final product.

Multilayer containers and tanks: Ultrasonic gauges can measure gas barrier and other layer thicknesses in multilayer bottles, food containers, fuel tanks, and similar products.

Fiberglass pipes and tanks: These products can be measured both in manufacturing and following installation to verify wall thickness and detect delaminations.

Fiberglass boats: Boat manufacturers and marine surveyors can measure hull thickness using high-penetration gauges if necessary for larger boats. Gelcoat thickness can also be measured with a second setup.

Composite structures: Aerospace composites in the form of wing and body panels, radomes, and similar fabrications can be measured for thickness and tested for delaminations with simple ultrasonic gauges.

9.4 Precision Ultrasonic Gauging—Other Materials

In addition to measuring common metals and plastics, ultrasonic gauges can be used in a wide variety of other applications, only a few of which are listed here

Rubber products: Sound attenuation in rubber is typically high in comparison to other materials, but thickness can usually be measured with high-penetration gauges. Common applications include wall thickness of rubber tubing, total thickness and depth of reinforcement in rubber conveyor belts, and tread thickness in tires.

Ceramics: Most structural and electronic ceramics are well suited for ultrasonic gauging, including ceramic tubing, containers, turbine blades and valves, and ceramic coatings. Ultrasonic gauges can also be used for testing elastic modulus measurement by means of sound velocity measurement.

Glassware: Glass is typically highly transmissive to sound waves. Glass containers, small-diameter glass tubing, scientific glassware, light bulbs, glass coatings, and similar products can all be measured.

Liquid level: Ultrasonic gauges can frequently measure the height or depth of liquids inside sealed containers and in situations where traditional methods such as dipsticks or calibration floats cannot be employed. Go/no go techniques can often be used to determine the presence or absence of liquid at a particular point in a tank or other container.

Soft contact lenses: It is possible to ultrasonically measure the thickness of soft contact lenses, which are difficult to measure mechanically without distorting their shape and also calculate base curve from an ultrasonic measurement of sagittal height.

Wax patterns: The thickness of the wax patterns used to create molds for turbine blades and similar precision products in the lost wax casting process can be measured, including the thickness of wax over ceramic cores.

Biological samples: Thickness of soft tissue such as skin, muscle, fat, and blood vessel walls can frequently be measured in biomedical research applications.

10. Appendices

10.1 Material Sound Velocities

The table below lists typical longitudinal wave ultrasonic velocities in various common materials that can be measured with ultrasonic thickness gauges. Note that this is only a general guide. The actual velocity in these materials may vary significantly due to a variety of causes, such as specific composition or microstructure, grain or fiber orientation, porosity, and temperature. This is especially true in the case of cast metals, fiberglass, plastics, and composites. For the best accuracy in thickness gauging, the sound velocity in a given test material should always be measured by performing a velocity calibration on a sample of known thickness.

Ultrasonic Velocities in Common Materials

Material	V (in./µsec)	V (m/sec)
Acrylic (Perspex)	0.1070	2730
Aluminum	0.2490	6320
Beryllium	0.5080	12900
Brass	0.1740	4430
Composite, graphite/epoxy	0.1200	3070
Copper	0.1830	4660
Diamond	0.7090	18000
Fiberglass	0.1080	2740
Glycerin	0.0760	1920
Inconel®	0.2290	5820
Iron, Cast (soft)	0.1380	3500
Iron, Cast (hard)	0.2200	5600
Iron oxide (magnetite)	0.2320	5890
Lead	0.0850	2160
Lucite®	0.1060	2680
Molybdenum	0.2460	6250
Motor oil	0.0690	1740
Nickel, pure	0.2220	5630
Polyamide	0.0870	2200
Nylon	0.1020	2600
Polyethylene, high density (HDPE)	0.0970	2460
Polyethylene, low density (LDPE)	0.0820	2080
Polystyrene	0.0920	2340
Polyvinyl chloride (PVC)	0.0940	2395
Rubber, polybutadiene	0.0630	1610
Silicon	0.3790	9620
Silicone	0.0580	1485
Steel, 1020	0.2320	5890
Steel, 4340	0.2300	5850
Steel, 302 austenitic stainless	0.2260	5740
Tin	0.1310	3320
Titanium	0.2400	6100
Tungsten	0.2040	5180
Water (20 °C or 68 °F)	0.0580	1480
Zinc	0.1640	4170
Zirconium	0.1830	4650

10.2 Generalized Material—Transducer Range Charts

The tables in this section list some typical materials and thickness ranges that can be measured with ultrasonic gauges, using specific transducers and appropriate instrument setups. These tables are intended only as a general guideline and list only some of the most common applications for metals and plastics. There are many more possibilities. If you need information regarding a specific thickness measurement that is not listed here, please contact Olympus.

All thickness ranges are approximate. The actual measurement range in a given case will always depend on instrument setup as well as specific material properties such as part geometry, surface condition, and microstructure. Material is assumed to be at ambient temperature. In all materials, attenuation increases with temperature, so at elevated temperatures the maximum measureable thickness will normally be lower, especially in plastics.

English Units

Notes: All thickness ranges are approximate. The actual measurement range in a given case will always depend on instrument setup as well as specific material properties such as part geometry, surface condition, and microstructure. The maximum thickness in plastics in Mode 1 measurements will vary depending on the type of plastic, so only a minimum is listed. These charts cover only some of the most common transducers and measurement situations. There are many other possibilities. For details, please contact Olympus.

Transducer (Frequency, Diameter, Type)	Measurement Mode	Range (Metal)	Range (Plastic)
20 MHz, 0.125 in. contact	1	0.020–1.5 in.	0.008 in. minimum
10 MHz, 0.25 in. contact	1	0.030–10 in.	0.010 in. minimum
5 MHz, 0.5 in. contact	1	0.050–20 in.	0.025 in. minimum
2.25 MHz, 0.5 contact	1	0.080–20 in.	0.050 in. minimum
1 MHz, 1 in. contact	1	0.150–25 in.	0.100 in. minimum
0.5 MHz, 1 in.	1	0.250–25 in.	0.200 in. minimum
20 MHz, 0.125 in. delay line	2	0.010–0.400 in.	0.005–0.200 in.
20 MHz, 0.125 in. delay line	3	0.008–0.200 in.	-
10 MHz, 0.25 in. delay line	2	0.020–0.750 in.	0.012–0.250 in.
10 MHz, 0.25 in.delay line	3	0.010–0.500 in.	-
5 MHz, 0.5 in. delay line	2	0.050–1.00 in.	0.040–0.500 in.
5 MHz, 0.5 in. delay line	3	0.050–0.500 in.	-
2.25 MHz, 0.5 in. delay line	2	0.080–1.00 in.	0.060–0.500 in.
2.25 MHz, 0.5 in. delay line	3	0.060–0.500 in.	-
10 MHz, 0.3 in. dual	dual	0.020–1.00 in.	-
5 MHz, 0.4 in.dual	dual	0.040–20 in.	-
2 MHz, 1 in.dual	dual	0.150–25 in.	-

Metric Units

Notes: All thickness ranges are approximate. The actual measurement range in a given case will always depend on instrument setup as well as specific material properties, such as part geometry, surface condition, and microstructure. The maximum thickness in plastics in Mode 1 measurements will vary depending on the type of plastic, so only a minimum is listed. These charts cover only some of the most common transducers and measurement situations. There are many other possibilities. For details, please contact Olympus.

Transducer (Frequency, Diameter, Type)	Measurement Mode	Range (Metal)	Range (Plastic)
20 MHz, 3 mm contact	1	0.5–40 mm	0.2 mm minimum
10 MHz, 6.25 mm contact	1	0.75–250 mm	0.25 mm minimum
5 MHz, 12.5 mm contact	1	1.25–500 mm	0.6 mm minimum
2.25 MHz, 12.5 mm contact	1	2–500 mm	1.25 mm minimum
1 MHz, 25 mm contact	1	3.75–650 mm	2.5 mm minimum
0.5 MHz, 25 mm contact	1	6–650 mm	5.0 mm minimum
20 MHz, 3 mm delay line	2	0.25–10 mm	0.125–5.0 mm
20 MHz, 3 mm delay line	3	0.2–5 mm	-
10 MHz, 6.25 mm delay line	2	0.5–20 mm	0.3–6.25 mm
10 MHz, 6.25 mm delay line	3	0.25–12.5 mm	-
5 MHz, 12.5 mm delay line	2	1.25–25.0 mm	1.0–12.5 mm
5 MHz, 12.5 mm delay line	3	1.25–12.5 mm	-
2.25 MHz, 12.5 mm delay line	2	2.0–25.0 mm	1.5–25.0 mm
2.25 MHz, 12.5 mm delay line	3	1.5–12.5 mm	-
10 MHz, 7 mm dual	dual	0.5–25.0 mm	-
5 MHz, 10 mm dual	dual	1.0–500 mm	-
2 MHz, 25 mm dual	dual	3.75–635 mm	-

10.3 Ultrasonic Thickness Gauging Glossary

Accuracy: The agreement between the measured value and the true value of a parameter such as thickness.

Acoustic Impedance: A material property defined as sound velocity multiplied by density. The amount of sound reflection at a boundary between two materials is derived from the ratio of acoustic impedances.

Amplitude: In wave motion, the maximum displacement of material particles. In electronics, the magnitude of a signal, normally expressed as a positive or negative voltage.

Attenuation: The loss in acoustic energy that occurs between any two points in a sound path.

Back Wall Echo: The echo received from the side of the test specimen opposite the side to which the transducer is coupled. The timing to this echo corresponds to the thickness of the specimen at that point.

Contact Transducer: A transducer designed to be used in direct contact with the test material.

Couplant: A material, usually a liquid or gel, used between the transducer and test piece to eliminate air and facilitate the coupling of sound energy.

Delay Line: A material (usually a plastic) placed in front of a transducer to create a time delay between the excitation pulse and the echo from the front surface of the test piece.

Delay Line Transducer: A transducer incorporating a delay line.

Dual Element Transducer: A transducer with separate transmitting and receiving elements, commonly used in corrosion measurements.

Excitation Pulse: A brief electrical pulse applied to a piezoelectric element in an ultrasonic transducer, causing it to vibrate and generate sound waves. Also known informally as the "main bang".

Frequency: The number of cycles of vibration experienced by an oscillating body in a designated period of time (normally one second). Electrically, the rate at which a periodic signal such as a sine wave repeats during a designated period of time.

Gain: In an ultrasonic gauge, the increase in signal strength produced by an amplifier, usually expressed as the ratio of output power to input power in decibels.

Immersion Testing: A test method in which sound energy is coupled between the transducer and test piece through a water column or water bath.

Immersion Transducer: A transducer designed to be used for immersion testing.

Interface Echo: The echo reflected from the front surface of a test specimen, seen when using delay line or immersion transducers.

Longitudinal Wave: The wave propagation mode normally used for ultrasonic gauging, characterized by particle motion parallel to the direction of wave travel. Audible sound waves are also longitudinal waves.

Measurement Mode: The method of timing echoes in thickness gauging, commonly differentiated as Modes 1, 2, and 3.

10.3 Ultrasonic Thickness Gauging Glossary

Phase Reversal: An inversion of the positive and negative peaks of a wave.

Range: The interval between the maximum and minimum thicknesses that can be measured in a material with a given transducer and instrument setup.

Resolution: In thickness gauging, the degree to which slightly different thicknesses or time intervals can be distinguished.

Sound Velocity: The speed at which a sound wave travels through a given material.

Sound Wave: A coherent pattern of mechanical vibrations in a solid, liquid, or gaseous medium.

Transducer: A device that transforms one form of energy into another. In ultrasonic testing this normally means converting electrical energy into mechanical energy or vice versa.

Ultrasonic: Referring to sound waves at frequencies above the limit of human hearing, generally defined as 20,000 cycles per second (20 kHz).

Waveform: A graphic presentation of energy levels in a wave train, plotted as amplitude versus time.

Zero Offset: A correction factor representing the difference between a measured time interval and the actual sound transit time in a test specimen, typically accounting for switching delays, cable delays, and wearplate and couplant thickness.

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