Multimedia

Ultrasonic Thickness Gaging

by Tom Nelligan

Ultrasonic thickness gaging is a widely used nondestructive test technique for measuring the thickness of a material from one side. It is fast, reliable, and versatile, and unlike a micrometer or caliper it requires access to only one side of the test piece. The first commercial ultrasonic gages, using principles derived from sonar, were introduced in the late 1940s. Small, portable instruments optimized for a wide variety of test applications became common in the 1970s. Later advances in microprocessor technology led to new levels of performance in today's sophisticated, easy-to-use miniature instruments.

1. What can be measured

Virtually any common engineering material can be measured ultrasonically. Ultrasonic thickness gages can be set up for metals, plastics, composites, fiberglass, ceramics, and glass. On-line or in-process measurement of extruded plastics and rolled metal is often possible, as is measurement of individual layers or coatings in multilayer fabrications. Liquid levels and biological samples can also be measured. Ultrasonic gaging is always completely nondestructive, with no cutting or sectioning required.
Materials that are generally not suited for conventional ultrasonic gaging because of their poor transmission of high frequency sound waves include wood, paper, concrete, and foam products.

2. How ultrasonic thickness gages work

Sound energy can be generated over a broad frequency spectrum. Audible sound occurs in a relatively low frequency range with an upper limit around twenty thousand cycles per second (20 Kilohertz). The higher the frequency, the higher the pitch we perceive. Ultrasound is sound energy at higher frequencies, beyond the limit of human hearing. Most ultrasonic testing is performed in the frequency range between 500 KHz and 20 MHz, although some specialized instruments go down to 50 KHz or lower and as high as 100 MHz. Whatever the frequency, sound energy consists of a pattern of organized mechanical vibrations traveling through a medium such as air or steel according to the basic laws of wave physics.

Ultrasonic thickness gages work by very precisely measuring how long it takes for a sound pulse that has been generated by a small probe called an ultrasonic transducer to travel through a test piece and reflect back from the inside surface or far wall. Because sound waves reflect from boundaries between dissimilar materials, this measurement is normally 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 gage listens for the echo from the opposite side. Typically this time interval is only a few millionths of a second. The gage 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) x (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

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 gage to the speed of sound in the material being measured, and accuracy can be only as good as this calibration.

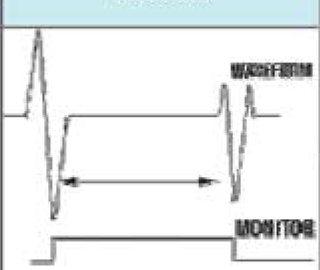
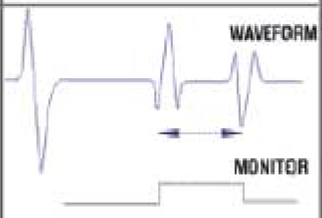
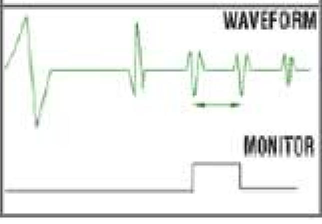
Sound waves in the megahertz range do not travel efficiently through air, so a drop of coupling liquid is used between the transducer and the test piece in order to achieve good sound transmission. Common couplants are glycerin, propylene glycol, water, oil, and gel. Only a small amount is needed, just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

3. Measurement modes

There are three common ways of measuring the time interval that represents the sound wave's travel through the test piece. Mode 1 is the most common approach, simply measuring the time interval between the excitation pulse that generates the sound wave and the first returning echo and subtracting a small zero offset value that compensates for fixed instrument, cable, and transducer delays. Mode 2 involves measuring the time interval between an echo returned from the surface of the test piece and the first backwall echo. Mode 3 involves measuring the time interval between two successive backwall echoes.

The type of transducer and specific application requirements will usually dictate the choice of mode. Mode 1, used with contact transducers, is a general purpose test modeand is recommended for most applications. Mode 2, used with delay line or immersion transducers, is most often used for measurements on sharp concave or convex radiuses or in confined spaces with delay line or immersion transducers, for on-line measurement of moving material with immersion transducers, and for high-temperature measurements with high-temperature delay line transducers. Mode 3, also used with delay line or immersion transducers, typically offers the highest measurement accuracy and the best minimum thickness resolution in a given application,at the expense of penetration It is commonly used when accuracy and/or resolution requirements cannotbe met in Mode 1 or 2. However Mode 3 can be used only on materials that produce clean multiple backwall echoes, typically low attenuation materials like fine grain metals, glass, and most ceramics.

Figure 2
Precision Ultrasonic Gauging Techniques Classified by the Echoes Used to Make the Time Interval Measurement

Mode	Waveform	Applicable Transducer Types	Applicable Range of Thickness Measurement (Steel)*	Approximate Accuracy Limits
1		Direct Contact	≈ 0.3 mm to 2.5M ≈ ≈ 0.012 in. to 100 in. ≈	±.01 mm ±.001 in.
2		Delay Line, I mmersion	≈ 0.5 mm to ≈ 10 cm ≈ 0.02 in. to ≈ 4 in	±.002 mm ±.0001 in.
3		Delay Line, I mmersion	≈ 0.1 mm to ≈ 4 cm ≈ 0.004 in. to ≈ 1.5 in	±.002 mm ±.0001 in.

4. Gage types

Commercial ultrasonic thickness gages are generally divided into two types: corrosion gages and precision gages. The single most important application for ultrasonic gaging is measuring the remaining wall thickness of metal pipes, tanks, structural parts, and pressure vessels that are subject to internal corrosion that can't be seen from the outside. Corrosion gages are designed for this type of measurement, using signal processing techniques that are optimized for detecting the minimum remaining thickness in a rough, corroded test piece, and they use specialized dual element transducers for this purpose.

Precision gages that use single element transducers are recommended for all other applications, including smooth metals as well as plastics, fiberglass, composites, rubber, and ceramics. With a wide variety of transducers available, precision gages are extremely versatile and in many cases can measure to an accuracy of +/- 0.001" (0.025 mm) or greater, higher than the accuracy that can be achieved with corrosion gages.

5. Transducer types

Contact transducers: As the name implies, contact transducers are used in direct contact with the test piece. Measurements with contact transducers are often the simplest to implement and they are usually the first choice for most common thickness gaging applications other than corrosion gaging.

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 backwall 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 on-line or in-process measurement of moving product, for scanned measurements, or for optimizing coupling into sharp radiuses, grooves, or channels.

Dual element transducers: Dual element transducers, or simply "duals", are used primarily for measurement of rough, corroded surfaces with corrosion gages. The incorporate separate transmitting and receiving elements mounted on a delay line at a small angle to focus 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.

6. Other things to consider

In any ultrasonic gaging application, the choice of gage and transducer will depend on the material to be measured, thickness range, geometry, temperature, accuracy requirements, and any special conditions that may be present. Olympus NDT can provide full details for specific applications. Listed below are the major factors that should be considered.

Material: The type of material and the range of thickness being measured are the most important factors in selecting a gage 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 gages with pulser/receivers optimized for low frequency operation.

Thickness: Thickness ranges will also dictate the type of gage and transducer that should be selected. In general, thin material 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 decreases the size of the transducer should generally be decreased as well. 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. 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.

Phase Reversal: There are occasional applications where a material of low acoustic impedance (density multiplied by sound velocity) is bonded to a material of higher acoustic impedance. Typical examples include plastic, rubber, and glass coatings on steel or other metals, and polymer coatings on fiberglass. In these cases the echo from the boundary between the two materials will be phase reversed or inverted with respect to the echo obtained from an air boundary. This condition can normally be accommodated by a simple setup change in the instrument, but if it is not taken into account, readings may be inaccurate.

Accuracy: Many factors affect measurement accuracy in a given application, including proper instrument calibration, uniformity of material sound velocity, sound attenuation and scattering, surface roughness, curvature, poor sound coupling, and backwall non-parallelism. All of these factors should be considered when selected a gage and transducer. With proper calibration, measurements can usually be made to an accuracy of +/- 0.001" or 0.01 mm, and in some cases accuracy can approach 0.0001" or 0.001 mm. Accuracy in a given application can best be determined through the use of reference standards of precisely known thickness. In general, gages using delay line or immersion transducers for Mode 3 measurements are able to determine the thickness of a part most precisely.

5. For further information

A more detailed discussion of the principles of ultrasonic gaging can be found in our **Thickness Gage Tutorial** on this web site. Also see individual application notes for discussions of particular test procedures.

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