NDT

NDT INTERNATIONAL, INC.
711 S. CREEK ROAD
WEST CHESTER, PA 19382

Tel: 610.793.1700 Fax: 610.793.1702
E-mail: info@ndtint.com

BASIC ULTRASONIC PRINCIPLES

SECTION 1.0: GENERAL OPERATION

1.1 GENERAL

The standard ultrasonic instrument is used for nondestructive flaw testing and thickness gauging of metallic and nonmetallic materials. The instrument uses the principles of sound propagation to detect, locate and evaluate defects such as cracks, porosity, deterioration, corrosion, and foreign inclusions found in material. It is also used for thickness gauging of material, to determine the location of defects, and to measuring the physical thickness of the test object.

By measuring transmission and attenuation properties, the UT scope can be used as an aid to certain physical and metallurgical characteristics of the material under test. The tester can operate in the normal mode or in the thru-transmission mode (dual transducer). The instrument is usually capable of performing direct contact (straight or angle beam) or immersion testing examination and can be used with single, dual element or delay line transducers.

The UT scope consists of a tester mainframe with a battery charger, and a power cable. The unit is usually self-contained, housed in a sturdy drip-proof and dust-proof enclosure and is provided with a handle for portability. The handle also serves to position the tester at a fixed angle inclination to improve viewing of the cathode ray tube (CRT) during operation. A front cover protects the face of the CRT and all operating controls from damage during shipment and handling.

1.2 ULTRASONIC PRINCIPLES

The UT scope mainframe generates ultrasonic vibrations and sends them through the test object in a beam of short bursts of energy. Any discontinuity in the path of the ultrasonic beam, as well as the far side of the test object, reflects the vibrations back to the instrument. The time required for the initial pulse to travel through this material and subsequently return as an echo is displayed on a cathode ray tube (CRT) as a thickness or distance measurement.

The sound waves are generated as recurrent changes in electrical voltage occurring at an ultrasonic rate, since it is above the audible range. Ultrasonic vibrations of lower frequencies act in essentially the same manner as audible sound waves. Ultrasonic waves of the higher frequencies behave somewhat like light waves. Ultrasonic vibrations have two basic characteristics:

a. They are reflected by discontinuities occurring in the medium thorough which they are traveling and,

b. They tend to travel in a straight line, as do light waves, due to the shortness of the wave length employed.

Ultrasonic waves can be propagated to some extent in any elastic material. This propagation, or traveling, of the waves occurs as a displacement of the successive elements of the medium. In any elastic substance there is a restoring force that tends to restore each element of material back to its original position after movement.

Since all elastic substances also possess inertia and momentum, the particle continues to move after it returns to the location from which it started and finally reaches another location past the original one. It will then continue back and fourth with a constantly diminishing amplitude. The particles of the material will execute different movements or orbits, as the wave passes through them. The overall effect is to attenuate the strength of the ultrasonic energy traveling through this medium.

Longitudinal, or compression, waves exist when the motions of the particles of a medium are parallel to the direction of wave travel. It is the type used when employing the straight beam technique of testing. This type wave is most often used in ultrasonic testing, since it will travel in liquids or solids, and is easily generated and detected. Longitudinal waves have a high velocity of travel in most materials, and the wave lengths in common materials are usually very short in comparison with the cross sectional area of the crystal used. This property allows the ultrasonic energy to be directed into a sharp beam, a fact that permits accurate location of defects.

When shear waves are generated in a material, the movements of the particles in that medium are at right angle to the direction of the wave propagation. They usually travel in a form of a beam of small cross section. Shear waves have a velocity that is approximately one-half that of the longitudinal waves. The shear wave is the type that is generated when using the angle beam technique of testing. Because of their lower velocity, the wavelength of shear waves is much shorter than that of longitudinal waves. This shorter wavelength makes them more sensitive to small discontinuities and they are more easily scattered within a material. Shear waves will not travel in gases or liquids, these materials being inelastic to shear and therefore incapable of supporting shear waves.

1.3 APPLICATION OF ULTRASONIC PRINCIPLES

All ultrasonic testers manufactured by NDT International, generate an electrical signal that changes at an ultrasonic frequency. A transducer utilizes the piezoelectric principle to convert the electrical energy into mechanical vibrations that penetrate through the material. Energy passing through the material is reflected partially by any discontinuities in its path or almost totally by the back surface. The vibrations sensed by the transducer are treated in a reverse manner to convert back to electrical energy, which is processed and displayed by the tester. The vibrations can be from discontinuities in the energy path or the multiple reflections from the back surface.

The scope will detect any appreciable discontinuity or lack of elasticity in a material under test. It will detect and locate holes or cracks within a solid of elastic material within sensitivity limits. The nature of the discontinuity that causes a variation in material elasticity does not influence the detection ability of the instrument. A drilled hole or a flaw such as a blowhole of equal projected area will be indicated in the same manner.

The size of defect that can be detected is also dependent upon the grain size of the material. If a part has a natural grain size of one-eighth inch diameter, it will be difficult to distinguish a one-eighth inch defect. The ultrasonic wave will be affected by these segregations without regard to the difference in size. To summarize, if the material is homogeneous except for the defects, or if the defects are larger than any natural discontinuity within the material, the tester will detect them, provided that there are not so many defects that the sound beam cannot penetrate the material.

SECTION 2: OPERATING TECHNIQUES

Of the various operating techniques used for ultrasonic flaw detection and thickness gauging, the method selected is determined by the geometry of the test object, location and orientation of the suspected defect, and the material characteristics. In some cases, multiple techniques are required for a complete investigation. The selection of the exact technique and transducer to be used are dependent on a number of factors that are interrelated.

The maximum signal amplitude from possible defects is obtained when the sound waves intercept the suspected defect perpendicular to the plane of the defect. Therefore, the factors that govern selecting the technique and the transducer should be based on the possible location of the defect that may occur in a given test object.

The physical geometry of the test object also determines the testing technique and the transducer to be used. There are five primary applications for the testing of materials using the instrument:

a. Straight-Beam (single transducer)
b. Straight-Beam (thru-transmission)
c. Angle-Beam
d. Immersion Testing
e. Thickness Gauging (single or dual element and delay-line)

2.1 STRAIGHT-BEAM, SINGLE TRANSDUCER (see Figure 3.1 & 3.2)

The single transducer (pulse-echo) technique is the simplest and most common form of flaw detection. Sound waves from the instrument are transmitted through the test object by a transducer and reflected back by the far side surface of the test object. The Initial Pulse (IP) appears on the left hand side of the CRT screen. The back-reflected pulse from the far side of the test object appears on the right hand side of the CRT screen. Presence of a flaw shows up as a reduced amplitude pulse anywhere between the initial pulse and the back reflected pulse. When a flaw is large enough to intercept the sound wave completely, there is no back-reflected pulse from the far side of the test object displayed on the CRT.

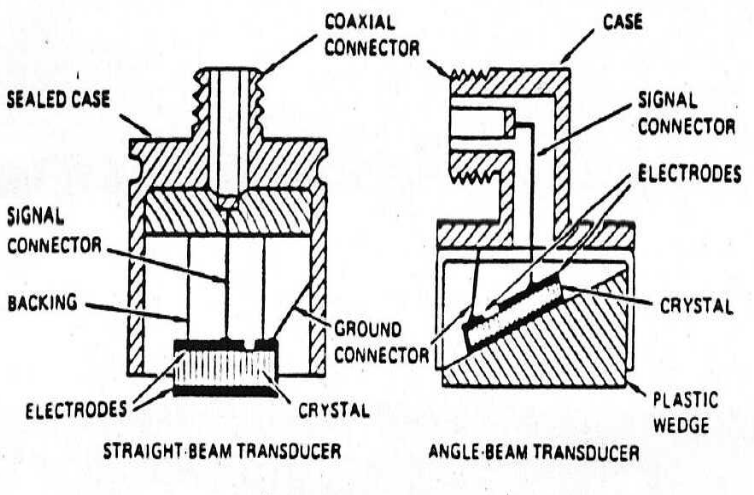


FIGURE 3.1: Construction of Straight Beam and Angle Beam Transducers

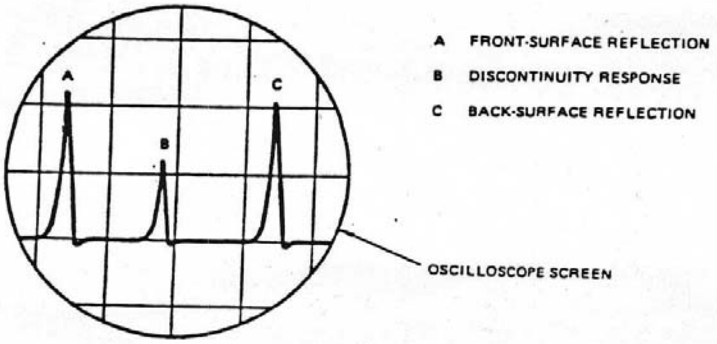
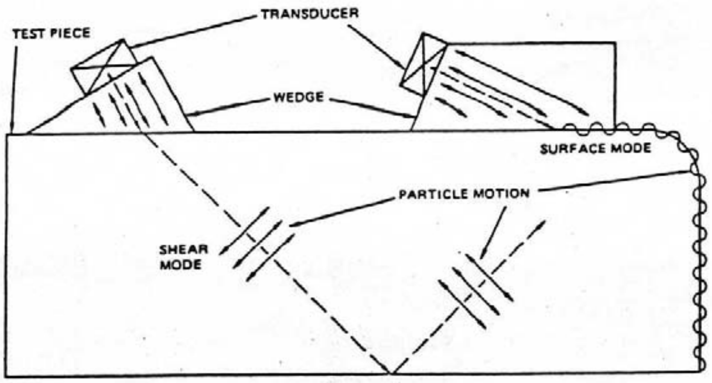


FIGURE 3.2: Typical CRT Display, Straight Beam, with One Transducer



NOTE THAT BEAMS ARE IN THE LONGITUDINAL MODE IN EACH WEDGE. MODE CONVERSION OCCURS WHEN THE SOUNDBEAM ENTERS THE TEST MATERIAL.

FIGURE 3.3: Angle Beam Transducers

2.2 STRAIGHT-BEAM, THRU TRANSMISSION

The thru-transmission technique requires two transducers; one operating as a transmitter, the other as a receiver, with each positioned at opposite sides of the test object. This technique is used where the geometry or internal condition of the test object prevents a round trip of the sound wave as described for the straight-beam technique. The initial pulse appears on the left hand side of the CRT screen and the received pulse appears at the right side of the screen. The presence of a flaw within the test object causes a reduction in amplitude of the sound wave pulse intercepted by the receiving transducer. Complete lack of a received sound wave pulse indicates that the flaw is large enough to block (or absorb) the transmitted sound wave completely.

2.3 ANGLE BEAM (See Figures 3.1 and 3.3)

The angle-beam (Shear Wave) technique is used for testing sheet, plate, pipe, & welds. A plastic wedge is placed between the test object and the transducer with a film of couplant between the transducer and wedge. The plastic wedge permits the sound wave to enter the test object at an angle. The sound-beam is then reflected back to the transducer as in straight-beam testing. The angle-beam technique without the plastic wedge can also be used in immersion testing.

An angle is selected to ensure that an echo is obtained from suspected flaws. These are often the most detrimental flaws, e.g. lack of fusion on welded sidewalls and at the root, or cracks. The probe angles most generally used for varying thickness of steel are as follows:

a. 70 Wedge - 0.250 to 0.750 inches in thickness
b. 60 Wedge - 0.500 to 2.00 inches in thickness
c. 45 Wedge - 1.500 and up in thickness

Probes operated at other angles have to be used, dependent upon the position of the flaw in the material under test, and for special cases in thinner sections. The frequency should be sufficiently low so as to avoid excessive attenuation.

2.4 IMMERSION TESTING (Fig. 3.4 & 3.5)

Immersion testing provides testing flexibility since the transducer can be moved underwater to introduce a sound wave at any desired angle. Immersion testing is suitable for high speed scanning systems because the transducer does not contact the test object and, therefore, is not subject to wear. The initial pulse appears on the left hand side of the CRT. A second pulse, immediately to the right of the initial pulse, of less amplitude, indicates the near surface of the test object.

The back-reflected pulse appears on the right hand side of the CRT screen. A flaw detected in the test object appears as a low amplitude pulse somewhere between the second pulse and the back reflected pulse on the CRT. For ease of interpretation, the initial pulse may be moved off screen.

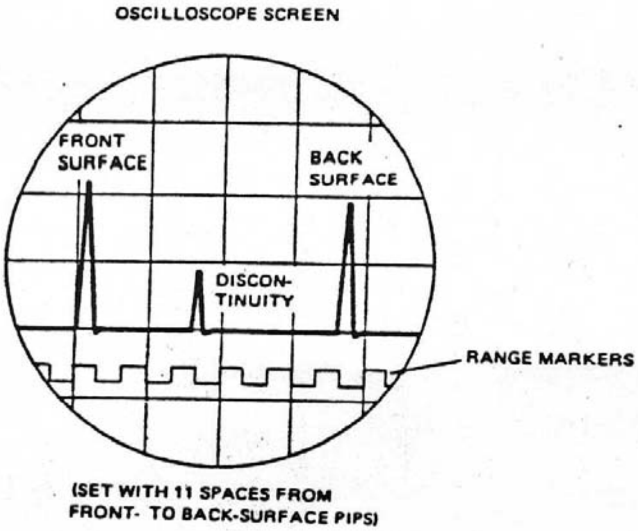


FIGURE 3.4: Typical CRT Display, Immersion Testing Usage

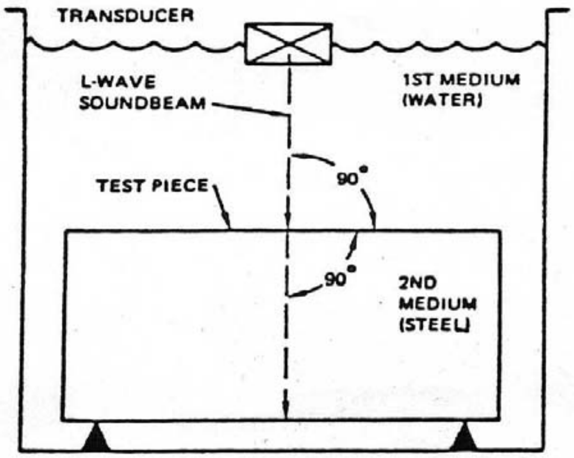


FIGURE 3.5: Immersion Testing, Straight Beam

2.5 THICKNESS MEASUREMENT

These measurement techniques are used to determine the thickness of an object. Single element, dual element or delay line transducers may be used for this technique. The instrument is first adjusted for a thickness range using comparison test blocks of the same material and material condition of the item under test. Then the instrument can reliably measure any unknown distance within this calibrated range. Delay line transducer thickness gauging permits measuring the thickness of thin samples.

2.6 INTRODUCTION TO ULTRASONIC THICKNESS GAUGING

Ultrasonic thickness gauging is a widely used technique for measuring the thickness of a material from one side. The first commercial ultrasonic gauges, using principles derived from sonar, were introduced in the late 1940's. Small portable instruments dedicated to a wide variety of applications became common in the 1970's.

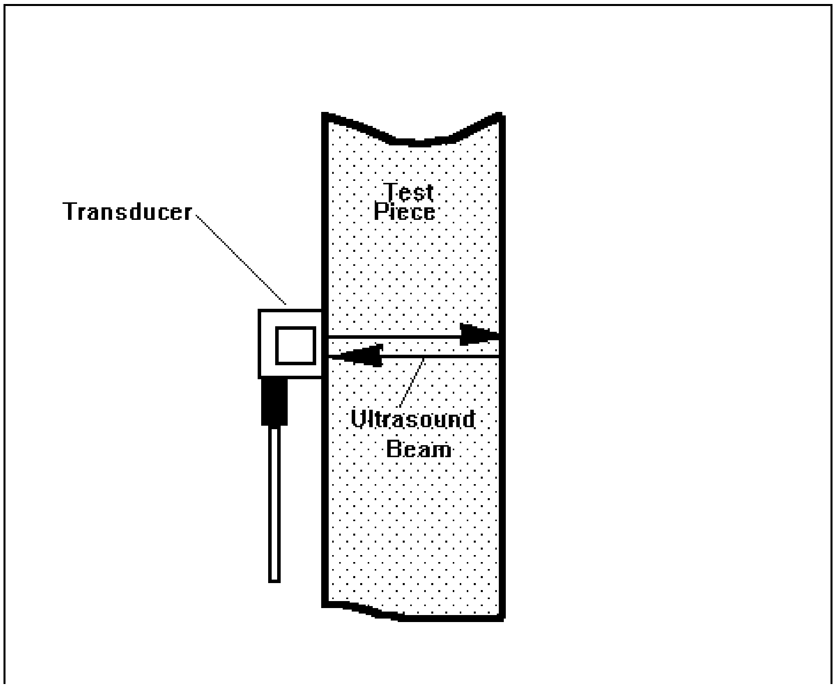
Sound energy can be generated over a broad frequency spectrum. Audible sound, for example, is restricted to a low frequency range with a typical upper limit of twenty thousand cycles per second (or 20 Kilohertz or KHz). Ultrasound is sound beyond the limit of human hearing - frequencies are too high to be detected by the human ear. Thickness gauges for industrial use operate at frequencies in the Megahertz range, typically from 1 to 20 MHz.

Ultrasound at high frequencies - because of its very short wave-length - has the advantage that it can make very accurate thickness measurements on most engineering materials. Even more important, measurements can be made from one side only as the ultrasound waves inside a material will bounce back from the opposite surface (like an echo). Thus, thickness measurements can be made instantly and accurately when the other side of the test part is impossible or difficult to reach, with no need to cut parts for access. Ultrasonic thickness measurements will save material, time, and labor costs.

A. HOW DOES IT WORK?

All ultrasonic measurements require two components: an electronic device (the gauge itself) and an ultrasonic transducer. In order to make a thickness measurement, the gauge transmits a pulse of electrical energy to the transducer, which then converts this energy into high frequency sound waves. This ultrasound enters the test material at the point of contact and propagates through the material until it reflects from the opposite surface. Some reflected sound will travel back to the point of entry, where it's detected by the same transducer. In essence, the transducer listens for the echo from the opposite side. In turn, the transducer converts sound energy into electrical energy. The electronic circuitry of the gauge then precisely measures the time interval between the initial pulse (or reference pulse) and the echo from the back wall. Typically, this time interval is a few millionths of a second. The gauge computes actual thickness of the test material by multiplying the time interval by the speed of sound in the material and then dividing this by two in order to compensate for the round-trip transit time.

It is important to note that the velocity of sound in the test material is an essential part of this computation. Different materials transmit sound at different velocities, and the sound velocity in some materials will change significantly with temperature or composition. Thus, it is always necessary to calibrate an ultrasonic instrument to the speed of sound in the test material at hand. Accuracy of a measurement will be only as good as this calibration.



It is practically impossible to efficiently transmit ultrasound from the transducer to the object to be measured without the aid of a suitable coupling medium, usually referred to simply as couplant. Couplants frequently used for thickness gauging are water, oil, gel, glycerin, and propylene glycol. In practice, a small amount of couplant is applied between the transmitting face of the transducer and the test surface.

B. WHAT MATERIALS CAN BE MEASURED?

Virtually any engineering material can be measured ultrasonically. Ultrasonic thickness gauges can be set up for metals, plastics, ceramics, composites, epoxies, and glass. Liquid levels and biological samples can also be measured. Materials generally not suited for conventional ultrasonic gauging include wood, paper, concrete, and foam products. On-line or in-process measurement of extruded plastics or rolled metal is often possible, as are layers or coatings in multi layer materials.

C. THINGS TO CONSIDER

For any ultrasonic gauging application, the choice of gauge and transducer will depend on the material to be measured, thickness range and accuracy requirements, geometry and temperature, and any special conditions that may be present. Listed below, in order of importance, are brief descriptions of some of the conditions that should be considered.

1. Materials

Material is the most important determinant in final selection of gauge and transducer. Certain materials, including most metals, glass, and ceramics, are excellent for sound propagation and lend themselves to a wide range of measurement modes and transducer frequencies.

Other materials, such as plastics, absorb ultrasound more quickly and have a limited measurable maximum thickness range. They are generally measured with gauges that utilize contact type transducers. Rubber, fiberglass, and composites are even more attenuating and often require gauges with special high penetration pulser/receivers and low frequency transducers.

2. Thickness Range

Thickness ranges will also dictate the type of gauge and transducer to be selected. In general, thin materials require high frequency transducers and thick or attenuating materials require lower frequencies. Very thin material may not be within the range of a gauge utilizing contact transducers; a delay line transducer may then be the answer. Similarly, gauges with delay line and immersion transducers have limited maximum thickness capabilities primarily due to potential interference from a multiple of the interface echo.

3. Geometry

A contract transducer is preferred for most ultrasonic measurements, unless sharp curvature or small part size makes contact measurements impractical. As the surface curvature of the test piece increases, the coupling efficiency from the transducer to the test piece is reduced. In general, as the surface curvature increases, the size of the contact transducer should be reduced. Extreme curvature or inaccessibility of the test surface requires a system with a delay line or an immersion transducer.

4. Temperature

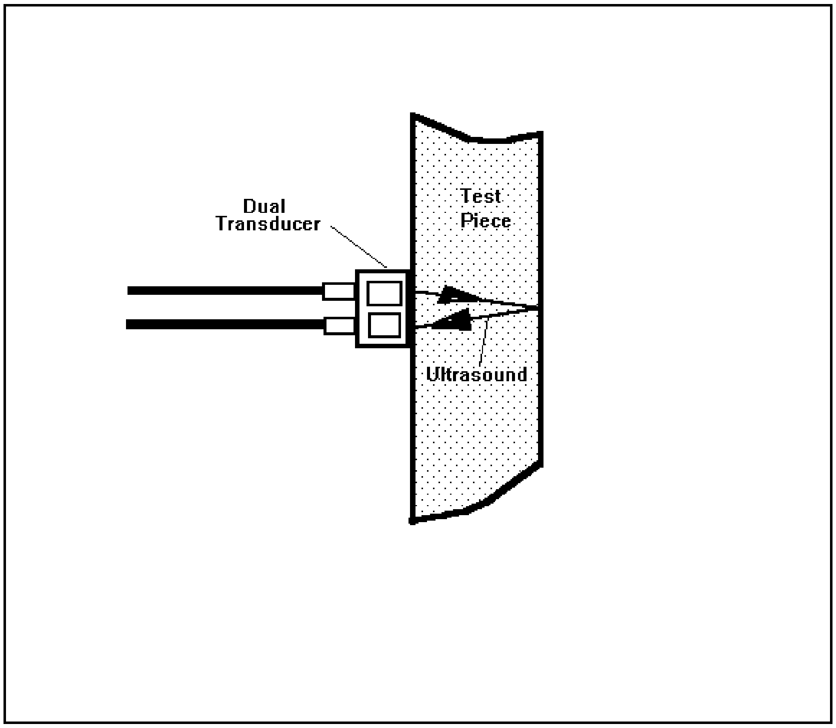
Contact transducers can be safely used on material surfaces up to 120^o F (50^o C). Thickness measurements with contact transducers on material surfaces In excess of these temperatures will result in transducer failure. Transducers with special heat-resistant delay lines are recommended on hot or warm surfaces especially if more than a few measurements will be taken.

5. Accuracy

It should be considered that many factors may affect accuracy: sound attenuation and scattering, sound velocity variations, poor coupling, surface roughness, non-parallelism, curvature, echo polarity, etc. Selection of the best possible combination of gauge and transducer should take into account all these factors. With proper calibration, measurements can usually be made to an accuracy of 0.001 inch or 0.01 mm.

D. THICKNESS GAUGING TRANSDUCERS

The most common application for thickness measurements involves "dual" or "pitch-catch" transducers. These employ separate transmitter and receiver transducer elements mounted on a delay line. The two-transducer elements are slightly angled towards each other, creating a V-shaped sound path beneath the surface of the part. Although measurement with dual transducers is not as accurate as with other types of measurements, they provide better performance on rough or corroded surfaces as found in pipelines, storage tanks, pressure vessels, structural support beams, and most other metal components exposed to the weather and extremes in temperature, pressure and humidity.



SECTION 3: THE TRANSDUCER

The instructions that follow are grouped into separate step-by-step procedures. As indicated by the titles of the procedures, a procedure must be selected for the task to be performed. Each procedure includes all steps and, unless otherwise indicated, does not require performance in consecutive order. In all cases, the procedure includes a calibration sequence; therefore, the standards used for calibration must be kept accessible with the instrument.

The specific operating sequence for the instrument is determined by the type of test to be performed. Each application may require a different combination of control settings. For this reason the following information does not give the optimum procedure and settings for all controls. The majority of these procedures are for calibration. When using the procedure operation none of the calibration controls are touched. An operational checkout is given as a simple test of equipment performance and to acquaint the operator with control functions.

3.1 TRANSDUCER SELECTION

An ultrasonic flaw and thickness scope may be used for testing many materials under a variety of test conditions, using selected test frequencies. For optimum results, the transducer must be selected to match the application. Table 3.1 shows typical transducer resolution.

TABLE 3.1 TYPICAL TRANSDUCER RESOLUTION

SELECTED FREQUENCY (MHz)	TRANSDUCER SIZE (Dia. Inches/mm)	ASTM HOLE SIZE (E-217-64)
1.0	2 (12.7mm)	8
2.25 (2)	5/16 (7.9375mm)	8
5.0	1/4 (6.35mm)	5
10.0	1/4 (6.35mm)	3
15.0 (delay line)	3/16 (9.525mm)	3

DISTANCE BELOW ENTRY SURFACE (Inches/mm)	FLAT PLATE THICKNESS (Inches/mm)
0.300 (7.62mm)	0.200 (5.08mm)
0.100 (2.54mm)	0.060 (1.524mm)
0.075 (1.905mm)	0.040 (1.016mm)
0.050 (1.27mm)	0.040 (1.016mm)
0.040 (1.016mm)	0.020 (0.508mm)

3.2 CONTACT TRANSDUCERS

Contact transducers are applied directly to the surface of the object under test to measure thickness or detect flaws. Applications include plate, bar, forgings, castings, and extrusions. Contact transducers have polished aluminum oxide wear plates that provide excellent wear resistance to assure long transducer life.

3.3 DELAY LINE CONTACT TRANSDUCERS

Delay line contact transducers are used primarily in thickness gauging where high resolution is required on thin materials such as sheet and tubing, or where test surface temperatures are very high, to insulate the transducer face. Delay tips do not have the same wear resistance as aluminum oxide therefore removable delay tips are available for replacement purposes. They can be easily shaped for gauging or inspecting curved surfaces.

3.4 DUAL ELEMENT TRANSDUCERS

Dual element transducers overcome the near-field problem of a single element probe. Dual elements tend to focus very close to the surface and are ideal for the detection of small pits and thickness gauging on corroded surfaces. Applications include flaw detection, thickness gauging and corrosion detection of thin materials, especially where near-surface contact resolution is desirable. A thickness of less than 0.050 inch (.127mm) can be readily resolved.

3.5 IMMERSION TRANSDUCERS

Immersion transducers are useful for examining irregularly shaped objects when submerged in a liquid in an inspection tank. They also make possible rapid continuous testing of materials (through an ultrasonic beam) by means of high-speed materials handling systems. The continuous testing of tubular products is an example of this. An immersion transducer generates a compression wave. However, since a column of water separates the object and the transducer, the transducer can be positioned so that angle beam testing can be conducted by directing the beam away from normal incidence to the entry surface of the test object. Also, lenses are available to focus the sound beam. Cylindrical, concave curvatures focus the sound energy to enter surfaces along a line focus. Spherical concave lenses focus the sound at a point.

3.6 ANGLE BEAM TRANSDUCERS

Angle beam transducers are modified contact transducers devised to direct the sound beam at an angle to the surface of a test object. This is accomplished with a plastic wedge. Angle beam transducers are used to test welded materials and in other applications where angular direction of the sound beam is essential. They are also valuable for detecting minute surface flaws in stressed or loaded surfaces such on aircraft wing spars, propeller blades and helicopter rotors. NDT International offers removable angle wedge so that different shear wave angles can be generated with a given angle-beam transducer.

3.7 BROADBAND TRANSDUCERS

Broadband, high damped, untuned transducers are recommended where high resolution flaw testing is a prime consideration. These transducers are also used for thickness gauging applications.

A transducer's resolving power is determined by the period required for vibration to stop after pulse excitation. Long-term vibration will cause an excessive front surface echo within the material being tested. If a transducer is poorly damped, the amplitude of the front surface echo will be greater than a small near-surface discontinuity and can cause the near surface discontinuity to be masked and remain undetected; therefore, it is essential that the transducers be highly damped where high resolution is mandatory.

Highly damped transducers respond over a broad band of frequencies, consequently they are responsive to frequencies extending above and below their nominal center frequency. This characteristic makes broadband transducers very useful for the inspection of material having large acoustical absorption or scattering effects. Note that the heavy damping required for broadband performance reduces the sensitivity of the transducer as much as 20 dB below a similar narrowband device.

Broadband transducers, when used with broadband pulser-receivers, permit the inspection of highly attenuative materials. Such materials might absorb high and center frequencies but continue to transmit low frequency components while still maintaining the advantages of high resolution. This would eliminate the necessity of having to shift to lower frequencies (i.e., a broadband 2.25 MHz transducer may receive frequencies as low as 0.5 MHz, whereas a narrowband 2.25 MHz transducer would not). Consequently, if it were necessary to shift to a 0.5 MHz narrowband transducer in order to achieve penetration, the effect of greater near-surface resolution achieved by the 2.25 MHz broadband transducer would be lost.

Broadband highly damped transducers approach near ideal (theoretical) damping conditions that are mandatory for error free thickness gauging. Single spike ½ cycle damping will produce accurate and dependable thickness measurements.

3.8 NARROWBAND TRANSDUCERS

Narrowband, moderately damped, untuned transducers provide material penetration, resolution, and high sensitivity and are recommended for the majority of ultrasonic flaw detection applications. They are ideal for flaw evaluation where known frequency specifications exist.

Since the sensitivity bandwidth product is limited in a narrowband transducer it has greater output at its nominal center frequency. Therefore, if the proper frequency for a given defect condition is selected, its detectability is far greater with a narrowband transducer than with a broadband transducer, which trades sensitivity for signal bandwidth.

Small defects tend to be frequency sensitive (i.e., a small crack will respond to only a narrow frequency range, while a flat bottom hole in a reference standard tends to respond to a wide range of frequencies). Therefore, if a broadband transducer is used for calibration on a flat bottom hole, and a material is inspected which contains a minute crack, the broadband transducer may not respond to (detect) the crack, whereas a frequency sensitivity narrowband transducer will.

Narrowband transducers contain matching tuning networks that are sealed within the transducer housing. Circuit tuning assures optimum frequency matching of transducer to the flaw detector that maximizes the sensitivity bandwidth product for flaw evaluation.

3.9 THE CORRECT TRANSDUCER

No single ultrasonic transducer is suitable for all applications. That is why NDT International offers a wide variety of types, sizes, frequencies, lenses and angles to meet practically every industrial requirement. Use this description as a guide to help you select the transducer that will meet your needs. If assistance is required in transducer selection, NDT International will be glad to provide it. NDT International also offers the services of its applications engineering department for the development and manufacturing of nonstandard transducers needed to solve unusual problems.

3.10 HANDLING THE TRANSDUCER

The transducer operates efficiently only when making contact over the full surface area of the transducer face. Obtaining the proper contact with the transducer is a simple matter; however, a few basic rules must be followed:

a. Cover the area of the surface to which the transducer is to be applied with a film of couplant.

b. Place the transducer on the testing surface gently. Do not bang it down; as such treatment may damage the crystal.

c. Rub the transducer face against the testing surface to get complete contact and to spread the couplant evenly over the surface.

d. Hold the transducer gently but firmly. Excessive pressure is not necessary. A loose grip may allow the transducer face to be cocked against the test surface so that only a small area will be in actual contact with the test sample.

e. Clean the surface of the material before using the transducer. If any dirt or foreign matter is felt beneath the transducer, clean and replace the couplant before placing the transducer on the material again.

f. Avoid running the transducer over small projections, or raised letting, etc., on the surface of material being tested.

g. Handle the transducer with care. Avoid dropping on the floor or bench. Do not leave it where other tools may damage it.

h. The transducer cable should also be treated with care. Avoid making sharp bends in the cable. When finished testing, clean and coil the cable.

SECTION 4: TYPICAL SCOPE CALIBRATION TESTS

4.1 VERTICAL LINEARITY

During this test REJECT must be OFF, as it will suppress small size echoes, giving erroneous linearity readings. Also, if they are present on the scope, the FLAW GATE and the DAC must be OFF. For this test a two inch (or 5 cm) steel reference block with a known defect halfway below the surface is used. The damping and gain controls are used to obtain a back wall reflection of six vertical divisions. The transducer is positioned to obtain a second echo (from the flaw) of three divisions. Some further adjustment of the damping and gain may be necessary so that the back wall reflection of six divisions and the flaw amplitude of three divisions is obtained. This adjustment produces a 2:1 (6dB) ratio between the echoes, which will be used to test linearity.

The transducer and damping controls are not touched for the remainder of this test. The Fine Gain control is now adjusted to give a back wall echo of ten, nine, then eight, etc. divisions down to two divisions, each time measuring the actual flaw amplitude and calculating the ratio. The set of ratios obtained is then plotted vs. the back wall amplitude to produce a Vertical Linearity graph.

4.2 HORIZONTAL LINEARITY

To measure the horizontal linearity set the range switch to 0.5 inches (2 cm) and use a steel test block of 0.2 to 0.5 (1 cm) inches. Adjust the scope to give at least two multiple back reflection echoes that have their leading edges rising sharply from the baseline. Using the Delay and Fine Range controls, adjust the display so that the leading edge of the first back reflection occurs at two horizontal divisions and the leading edge of the second back reflection occurs at seven horizontal divisions.

Measure the echo position as the leading edge breaks the baseline. Note that the distance from leading edge to leading edge of the echoes is twenty-five small CRT divisions. Record this distance. Using the Delay Control only, move the leading edge of the first echo to 0 divisions on the CRT. Note the point where the leading edge of the second echo falls and record this distance. Repeat this process, moving the first echo to one, three, four and five divisions, and recording the number of small divisions to the second echo. Plot the deviations from the correct twenty-five divisions vs. horizontal position on the screen to generate the Horizontal Linearity graph.

4.3 SENSITIVITY

Use a 5 MHz x 2" diameter transducer and a NAVSHIPS steel test block having 0.050" dia. cross-drilled holes at 12", 13", 1", 2", & 3" metal path. Verify the detectability of each hole and record the Coarse and Fine gain settings for each. This test verifies the flaw detection sensitivity of both the flaw detector and the transducer being used.

VELOCITY TABLE for common materials

	Longitudinal Velocity		Conversion Factor
Material	Inch/µSec	mm./µSec	from Mild Steel
ALUMINUM	.248	6.32	0.93
BERYLLIUM	.507	12.9	0.45
BRASS	.169	4.28	1.36
CADMIUM	.109	2.78	2.11
CAST IRON	.189	4.80	1.22
COPPER	.183	4.66	1.26
DIAMOND	.690	17.5	0.33
GLASS (Crown)	.207	5.26	1.11
GLASS (Window)	.267	6.79	0.86
GLYCERIN	.076	1.92	3.03
GOLD	.128	3.24	1.80
INCONEL	.225	5.72	1.02
IRON	.232	5.90	0.99
IRON (Cast)	.189	4.80	1.22
LEAD	.087	2.16	2.64
LUCITE	.106	2.68	2.17
MAGNESIUM	.248	6.31	0.93
MANGANESE	.183	4.66	1.26
MOLYBDENUM	.248	6.29	0.93
MONEL	.237	6.02	0.97
NEOPRENE	.063	1.60	3.65
NICKEL	.222	5.63	1.04
NYLON 6,6	.066	1.68	3.48
OIL (SAE 30)	.685	1.74	0.34
PHENOLIC	.559	1.42	0.41
PLATINUM	.156	3.96	1.47
PLEXIGLAS (UVA)	.109	2.76	2.11
PLEXIGLAS (UVA II)	.107	2.73	2.15
POLYETHYLENE	.105	2.67	2.19
POLYSTYRENE	.105	2.67	2.19
POLYURETHANE	.070	1.90	3.28
PORCELAIN	.220	5.60	1.04
RUBBER (Butyl)	.073	1.85	3.15
RUBBER (Vulcanized)	.090	2.30	2.55
SILVER	.142	3.60	1.62
STEEL (Mild) 4340	.230	5.85	1.00 (Standard Calibration)
STAINLESS STEEL	.225	5.80	1.02
TIN	.131	3.32	1.76
TITANIUM	.239	6.07	0.96
TUNGSTEN	.204	5.18	1.13
WATER	.584	1.48	0.39
ZINC	.164	4.17	1.40
ZIRCALOY 2	.187	4.65	1.23

EXAMPLE: At factory setting, the NDT 710 Thickness Gauge reads 0.630" when measuring a Copper plate. Since the velocity of copper is less than that of steel, the actual thickness would be less than the gauge display reading. Find the appropriate material in the above table and divide the gauge reading by the conversion factor (1.26 for Copper). This will convert the reading to the actual material thickness.

0.630". 1.26 = 0.500" (the Actual Thickness)