NDT Supply.com, Inc.
7952 Nieman Road
Lenexa, KS 66214-1560 USA

Phone: 913-685-0675, Fax: 913-685-1125
e-mail: sales@ndtsupply.com, www.ndtsupply.com

CHAPTER 5
ULTRASONIC INSPECTION METHOD

SECTION I GENERAL CAPABILITIES OF ULTRASONIC (UT) INSPECTION

5.1 INTRODUCTION.

5.1.1 Introduction to Ultrasonic Inspection. The term ultrasonic pertains to sound waves having a frequency greater than 20,000 Hz. For most ultrasonic nondestructive inspection, the ultrasound will be generated by a device called a transducer, which will be discussed at length later in this chapter. The more general term ‘‘search unit’’ is also used to refer to the device introducing ultrasound into a part. For purposes of this manual, the two terms are considered synonymous.

5.1.2 Development of Ultrasonics. Developments in submarine warfare in the mid-twenties created a need for underwater communication. Early research for a suitable communicating method led to the invention of sonar, underwater ranging, and depth indicating devices.

5.1.2.1 In the late thirties, considerable work was done in applying ultrasonic waves to nondestructive inspection of materials. The first instruments were considered to be laboratory items, and were mostly for metallurgical research. Since then, ultrasonics has come a long way. The need for ultrasonics has grown with the advancement of aircraft, materials, and technologies.

5.1.3 Ultrasonic Testing. Ultrasonics uses (ultra) sound to detect internal and external discontinuities ranging from cracks to disbonds. Ultrasound can be used on almost any material to locate discontinuities from large disbonds, down to the smallest defects. It can also be used to measure the overall thickness of a material, and the specific depth of a defect. The part requires little or no preparation; however, knowledge of the internal geometry of a part is critical to interpretation of any defect signal.

SECTION II PRINCIPLES AND THEORY OF ULTRASONIC INSPECTION

5.2 INTRODUCTION.

5.2.1 Characteristics of Ultrasonic Energy.

5.2.1.1 Characteristics of Sound. The transmission of both audible sound and ultrasound is characterized by periodic vibrations of molecules or other small volume elements of matter. The vibration propagates through a material at a velocity characteristic to that material. As a particle is displaced from its rest position by any applied stress, it moves to a maximum distance away from its rest position (this is called a maximum displacement). The particle then reverses direction and moves past its rest position to a maximum position in the negative direction (a second maximum displacement). The particle then moves back to its rest position, completing one cycle. This process continues until the source of vibration is removed and the energy is passed on to an adjacent particle. The amplitudes of vibration in parts being ultrasonically inspected impose stresses low enough, so that, there is no permanent effect to the part.

5.2.1.2 To better understand the characteristics of sound, you must understand the terms associated with ultrasonics.

5.2.1.2.1 The term “period” means the amount of time it takes to complete one cycle.

5.2.1.2.2 The term “velocity” means the distance traveled per unit time (distance/second).

5.2.1.2.3 The term “frequency” means the number of complete cycles that occur in one second.

5.2.1.2.4 The term “hertz” means the cycles per second. For example: 1 hertz (Hz) = one cycle/sec; 1 kilohertz (kHz) = 1,000 cycles/sec; 1 Megahertz (MHz) = 1,000,000 cycles/sec.

5.2.1.2.5 The term “wavelength” is the distance a wave travels while going through one cycle.

5.2.2 Generation and Receiving of Ultrasonic Vibrations.

Ultrasonic vibrations are generated by applying electrical energy to piezoelectric element contained within a transducer. This applied energy will be either a sudden high voltage spike from a discharging capacitor (a spike pulse), or a short pulse of constant voltage called a square wave. Also used where maximum power is needed from the transducer is a tone burst, which is a rapid series of square waves at a frequency matched to the transducer. The spike pulse is most commonly used. The transducer element transforms the electrical energy into mechanical energy (vibration) at a frequency determined by the material and thickness of the element. For aircraft NDI, this frequency will be ultrasonic. This element is also capable of receiving ultrasonic (mechanical) energy and transforming it into electrical energy (e.g., reverse piezoelectric) (Figure 5-1). Ultrasonic energy is transmitted between the transducer and the test part through a coupling medium (e.g., oil, grease, or water) (Figure 5-2). The purpose of a coupling material is to eliminate air at the interface between the transducer and the part under inspection. Air has high acoustic impedance, and thus, is a poor transmitter of ultrasound. Like audible sound waves, ultrasonic waves are capable of propagating through any elastic medium (solid, liquid, gas), but not in a vacuum. Propagation in any gas is very poor.

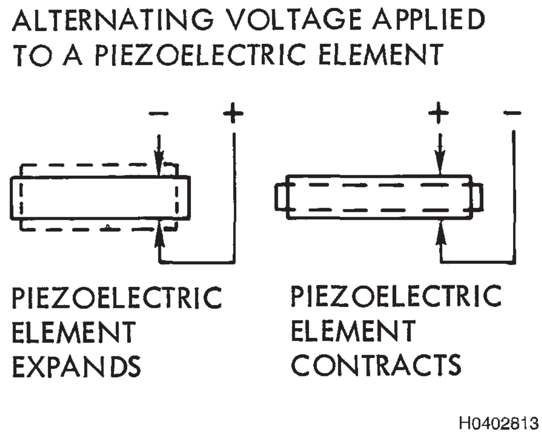


Figure 5-1. Generation of Ultrasonic Vibrations

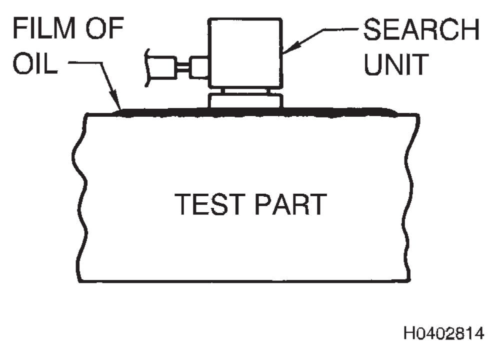


Figure 5-2. Coupling Between the Transducer and the Test Part to Transmit Ultrasonic Energy

5.2.3 Modes of Ultrasonic Vibration. Ultrasonic energy is propagated in a material by the vibration of particles in the material. The mode of vibration is dependent upon the direction in which the particles vibrate in relation to the propagation direction of the bulk ultrasonic beam. Ultrasonic waves are classified by the following modes of vibration: longitudinal, transverse, surface, and Lamb modes.

5.2.3.1 Longitudinal Waves. Waves in which the particle motion of the material moves in essentially the same direction as the sound wave propagation, are called longitudinal waves (also referred to as “compressional waves” or “L-waves”) (Figure 5-3). Longitudinal waves can be generated within solids, liquids, and gases. Longitudinal waves are generated in a part under inspection when an incident longitudinal wave is near normal (90°) to the surface of the part under inspection. The longitudinal wave velocity is determined by the material’s elastic modulus and density, and is a constant for each material. Longitudinal wave inspections are used extensively for thickness inspections, corrosion thinning, and for the detection of other defects parallel to the inspection surface.

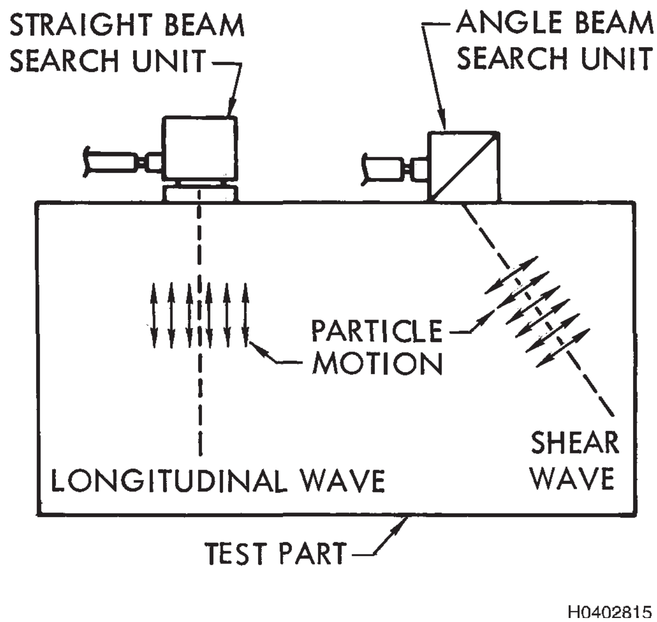


Figure 5-3. Longitudinal and Transverse Wave Modes

5.2.3.2 Transverse (Shear) Waves. Transverse (also known as “shear” or “s-wave”) waves denote the motion of waves in which the particle motion is perpendicular to the direction of propagation (Figure 5-3). These inspections are also called angle beam inspections. Shear waves travel at approximately 50-percent (half) of the velocity of longitudinal waves for the same material. Transverse waves can exist in any elastic solid, but are not supported by liquids or gases. Shear waves are generated in a test piece when a longitudinal wave impinges on the surface at an angle within a range of angles other than normal (90°) to the surface. This range is from the first to the second critical angles. These will be discussed at length later in this chapter. (The angle between the incident longitudinal wave and a line normal to the surface is referred to as the incident angle.) Part of the sound is reflected, but over a wide range of incident angles, part of the sound enters the test piece where mode conversion and refraction occur, resulting in a shear wave at an angle in the part. The portion converted to a shear wave will vary with the incident angle. Shear wave inspections are used extensively for crack and other defect inspections where the defect is suspected to be located at other than parallel to the inspection surface.

5.2.3.3 Surface (Rayleigh) Waves. Surface (Rayleigh) waves have a particle motion elliptical in a plane, parallel to the propagation direction, and perpendicular to the surface. Surface waves are generated when an incident longitudinal wave (paragraph 5.2.4.2) impinges on the test piece at an incident angle just beyond the second critical angle for that material. Once generated, surface waves can travel along curves and complex contours. Surface waves travel at approximately 90-percent of the velocity of shear waves for the same material. Surface waves are confined to a thin layer of the material under inspection, up to one wavelength deep, and can only be sustained when the medium on one side of the interface is a gas. An angle beam transducer containing a steeply angled wedge is shown in Figure 5-4. The energy of surface waves decays rapidly below the surface of a test part as shown in Figure 5-5. Surface waves are most suitable for detecting surface flaws, but may also be used to detect discontinuities lying up to one-half wavelength below the surface.

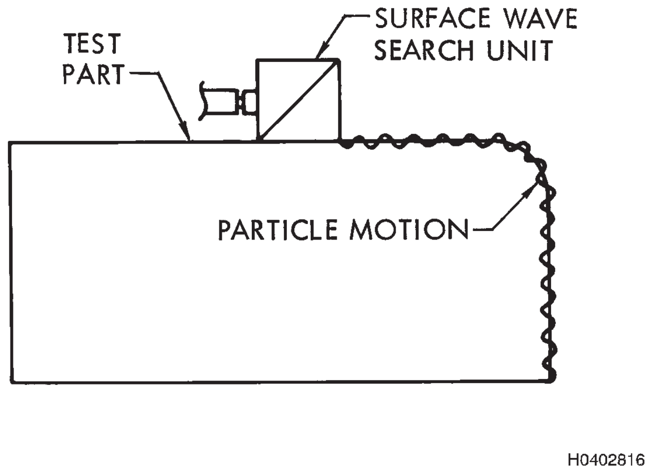


Figure 5-4. Surface Wave Mode

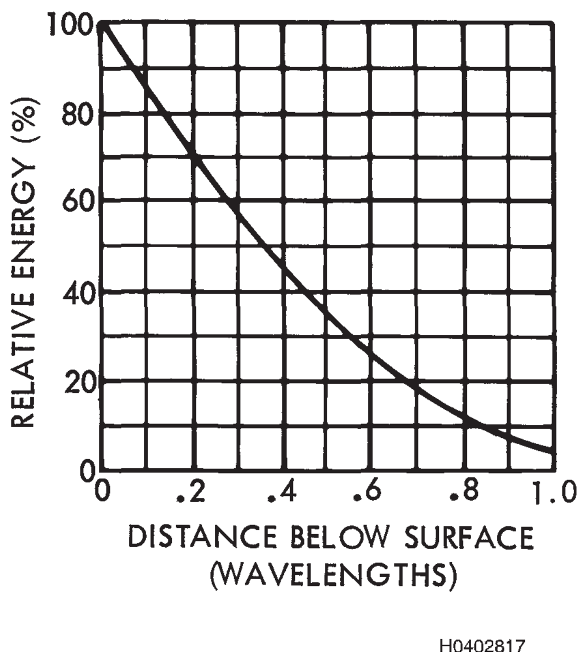


Figure 5-5. Distribution of Surface Wave Energy With Depth

5.2.3.4 Lamb (Plate) Waves. Lamb (plate) waves propagate within thin plates, a few wavelengths thick. Wave propagation is between the two parallel surfaces of the test piece, and can continue for long distances. Lamb waves are generated in a complex variety of modes. The propagation characteristics of Lamb waves are dependent on the properties and thickness of test material, as well as the test frequency. Two basic forms of Lamb waves exist symmetrical and asymmetrical. Although not widely used in production, Lamb waves are beneficial in large area inspection applications, such as corrosion and disbonds, because they can propagate for long distances.

5.2.4 Refraction and Mode Conversion.

5.2.4.1 Snell's Law. When an incident longitudinal beam is normal to the test part surface ($\theta_1 = 0°$), the longitudinal sound beam is transmitted straight into the test part and no refraction occurs. When the incident angle is other than normal; refraction, reflection, and mode conversion occur. Refraction is a change in propagation direction. Mode conversion is a change in the nature of the wave motion. A portion of the longitudinal incident beam is refracted into one or more wave modes traveling at various angles in the test piece (Figure 5-6). Wave refraction at an interface is defined by Snell's Law. The Snell's Law formula is located in (paragraph 5.7.2).

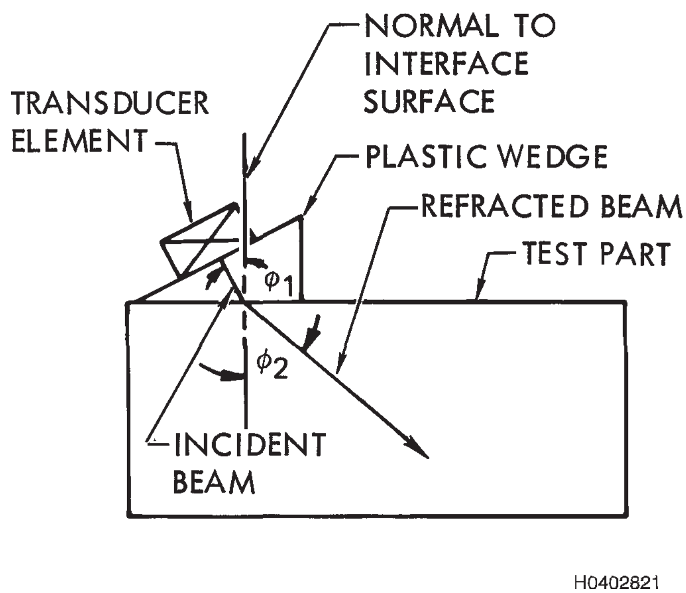


Figure 5-6. Sound Beam Refraction

5.2.4.2 Refracted Beam Energy. The relative energy for longitudinal, shear, and surface wave beams in steel, for different incident angles of longitudinal waves (paragraph 5.2.3.1) in plastic, is shown in Figure 5-7. The curves shown were obtained using plastic wedges on steel. Similarly shaped curves MAY be obtained for other test materials (i.e., aluminum and titanium). Similarly curves MAY also be generated for the immersion inspection (paragraph 5.4.2.1.1.2) in water. Refraction angles are greater in water than plastic.

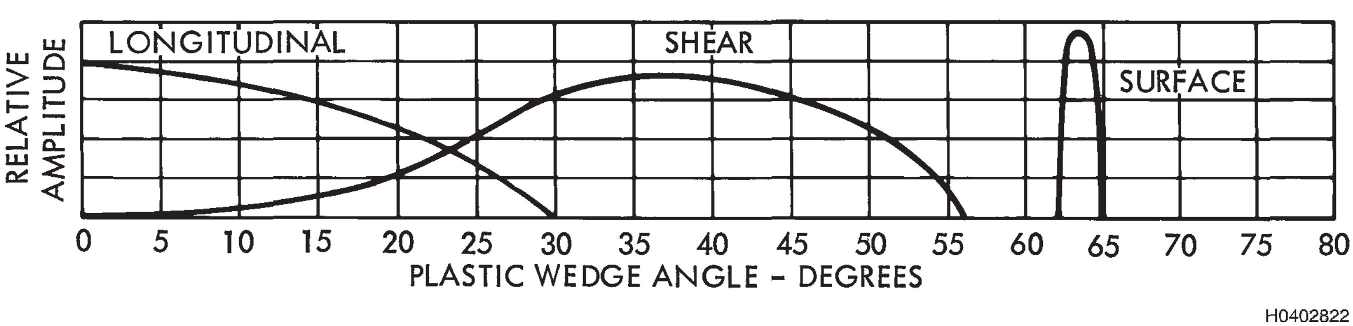


Figure 5-7. Relative Amplitude in Steel of Longitudinal, Shear, and Surface Wave Modes With Changing Plastic Wedge Angle

5.2.4.3 Multiple Refracted Beams. When an incident longitudinal beam is normal to the test part surface ($\theta_1 = 0°$), the longitudinal sound beam is transmitted straight into the test part and no refraction occurs. When the incident angle is other than normal, refraction and mode conversion occur. A portion of the longitudinal beam is refracted at some angle greater than 0° and is mode converted into one or more wave modes traveling at various angles and intensities, depending on the incident angle of the longitudinal beam. The angles of the refracted and mode converted beams are determined by Snell's law (paragraph 5.7.2). The relative energy for longitudinal, shear, and surface wave beams in steel, for different incident angles of longitudinal waves (paragraph 5.2.3.1) in plastic, is shown in Figure 5-7. The curves shown were obtained using plastic wedges on steel. Similarly shaped curves can be obtained for other test materials, such as aluminum and titanium. Similarly curves can also be generated for the immersion inspection (paragraph 5.4.2.1.1.2) with the plastic replaced by water. Refraction angles are greater with water than plastic.

5.2.4.3.1 Critical Angles. In angle beam inspection, it is important to know what types of waves and at what angles the waves exist in the test material. Because shear waves (paragraph 5.2.3.2) and longitudinal waves (paragraph 5.2.3.1) travel at different velocities in a given material, confusing signals can be generated and lead to false calls or missed indications.

5.2.4.3.1.1 First Critical Angle. The incident angle that yields a 90° refracted longitudinal wave is defined as the first critical angle. At incident angles equal to or greater than the first critical angle, longitudinal waves no longer exist in the material. Beyond this angle, only shear waves remain in the test material.

5.2.4.3.1.2 Second Critical Angle. The incident angle at which the refracted angle for shear waves reaches 90° is defined as the second critical angle. At incident angles equal to or greater than this, shear waves no longer exist in the material. Slightly beyond the second critical angle, surface waves (paragraph 5.2.3.3) are propagated along the surface of the material.

5.2.4.3.1.3 Most angle beam inspections are performed with only a shear wave present in the test material, therefore most incident angles useful for shear-wave inspection NDI fall between the two critical angles. The first critical angle in plastic for steel (Figure 5-7) is approximately 30°; the second critical angle is approximately 56°. For surface wave inspection the incident angle is purposely increased past the second critical angle to generate the desired surface wave.

5.2.4.4 Determining the Angle of Incidence in Plastic to Generate 45-Degree Shear Waves in Aluminum. Field NDI personnel are responsible for using the correct refracted beam angle for a particular application. The specific procedure details the correct refracted beam angle; however, it is important for the field NDI inspector to know how the correct angle was obtained. Snell's law is the tool for determining wedge angles for contact testing (paragraph 5.4.2.1.1.1), or the angle of incidence in water for immersion testing (paragraph 5.4.2.1.1.2). An example showing how Snell's law is used to determine the angle of incidence in plastic needed to generate 45° shear waves in aluminum is shown in paragraph 5.7.3.

5.2.5 Ultrasonic Inspection Variables. Ultrasonic inspection is affected by several variables. The ultrasonic inspection system consists of the instrument, transducer, wedges or shoes, coupling medium, etc. A discussion of variables related to the test part follows the paragraphs describing system variables. It is important the operator be familiar with and recognize the effects of all these variables.

5.2.5.1 Frequency. For flaw detection using the contact method (paragraph 5.4.2.1.1.1), frequencies between 2.25 MHz and 10 MHz are commonly used. The higher frequencies in this range provide greater sensitivity for detection of small discontinuities, but do not have the penetrating power of the lower frequencies. The higher frequencies can also be more affected by small metallurgical discontinuities in the structure. Signals from these discontinuities can often interfere with the detection of relevant discontinuities, such as small cracks. The size of the defect detected SHOULD be the prime consideration when selecting the inspection frequency. Typically, defects must have at least one dimension equal to or greater than 1/2 the wavelength in order to be detected. For example, straight beam (paragraph 5.3.2.3.1) inspection of aluminum at 2.25 MHz with a wavelength of 0.111-inch, requires a defect be 0.066-inch or larger in order to be detected (e.g., at 5 MHz, the minimum defect size is 0.025-inch and at 10 MHz, it is 0.012-inch).

5.2.5.2 Frequency Bandwidth. The above discussion on frequency pertains to the peak frequency used in an inspection. In all cases, the ultrasonic instrument and transducer produces a band of ultrasonic energy covering a range of frequencies. The range is expressed as bandwidth. Ultrasonic inspection procedures can be sensitive to frequency; therefore, the inspection results can be affected by variation in the bandwidth of the inspection system. For example, certain inspections use loss of back reflection as criteria for rejection. Frequencies too high can lead to diminished or complete loss of back reflection due to the sound being scattered by a rough inspection surface, large grain structure in the test material, or small irrelevant discontinuities. In other words, improper choice of peak frequency and bandwidth of the inspection system can produce irrelevant indications that affect inspection results. Both the instrument and the transducer affect the bandwidth of the inspection. Therefore, it is best to have a reference standard of the same material manufactured with the same manufacturing process and the same surface conditions as the test part, so the inspection results will be the same for different inspection systems. Instruments are constructed to pulse the transducer, and measure the response in different ways with respect to bandwidth.

5.2.5.2.1 Some instruments use a spike pulser and a broadband amplifier. With these instruments, the bandwidth is controlled by the transducer. A given transducer has a maximum response at the natural resonant frequency of the transducer element; however, the element will also respond at other frequencies. The transducer response to these other frequencies is controlled by its internal construction. Modern instruments are designed to be operated in either narrow band or broadband modes to accommodate a variety of transducers. A broad bandwidth means better resolution; and a narrow bandwidth means greater sensitivity. Ultrasonic systems are generally designed with respect to bandwidth to provide a reasonable compromise between resolution and sensitivity.

5.2.6 Sound Beam Characteristics. The sound beam does not propagate uniformly through the volume defined by the straight-sided projection of the transducer face. Side lobes exist along the outer edges of the beam near the transducer face, and sound intensity is not uniform throughout the beam.

5.2.6.1 Dead Zone. During contact testing (paragraph 5.4.2.1.1.1), there is test specimen thickness beneath the transducer in which no useful ultrasonic inspection can take place. This region is defined as the dead zone. When a transducer is excited, it vibrates for a finite amount of time during which it cannot act as a receiver for a reflected echo. Reflected signals from defects located in the dead zone arrive back at the transducer while it is still transmitting. A dead zone is inherent in all ultrasonic equipment. In some ultrasonic inspection equipment, the transmitted pulse length can be electronically shortened, effectively making the dead zone shallower, but it cannot be eliminated. The dead zone length can be estimated experimentally.

5.2.6.2 Near Field. Extending from the face of the transducer is an area characterized by wide variations in sound beam intensity. These intensity variations are due to the interference effects of spherical wave fronts emanating from the periphery of the transducer crystal. The region where this interference occurs is called the near field or Fresnel (pronounced Fray-nel) Zone (Figure 5-8). The equation for calculating the length of the near field is located in paragraph 5.7.5.

The smaller the transducer element diameter or the lower the frequency, the shorter the near field will be. Due to inherent amplitude variations, inspection within the near field is not recommended without careful calibration on reference flaws within the near field.

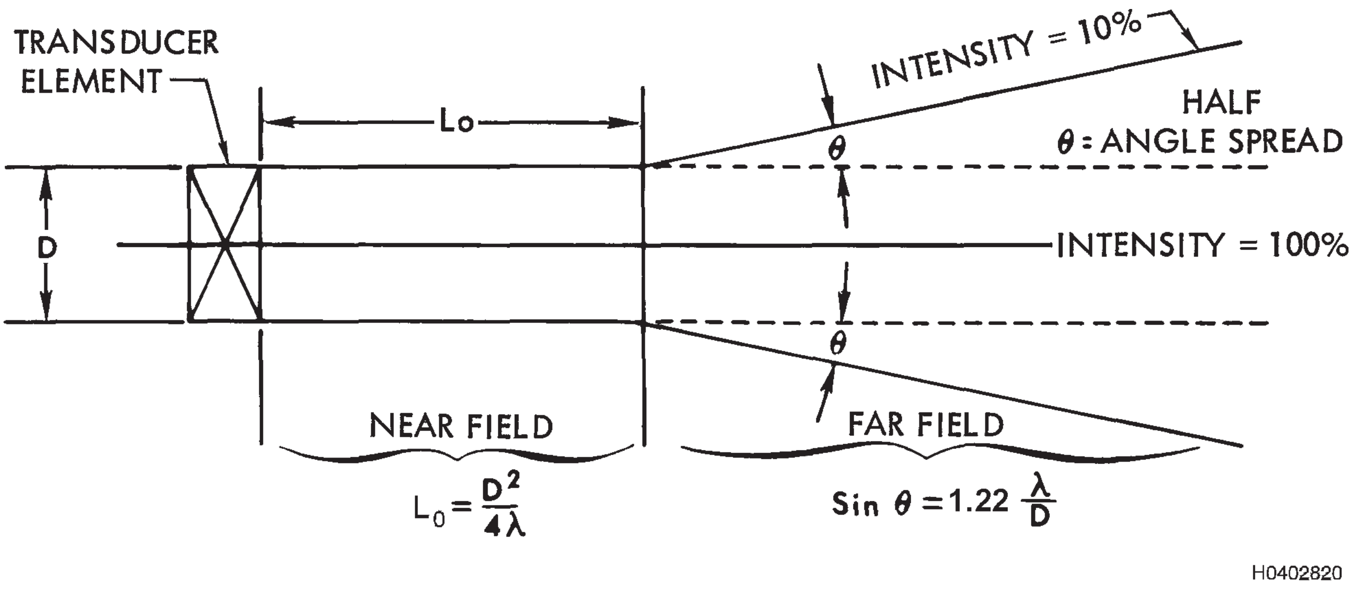


Figure 5-8. Schematic Presentation of Sound Beam

5.2.6.3 Far Field. At distances beyond the near field there are no interference effects. This region is called the far field (Fraunhofer Zone) (Figure 5-8). Most ultrasonic inspection procedures are designed to occur in the far field. The intensity of the sound beam in the far field falls off exponentially as the distance from the face of the transducer increases.

5.2.6.4 Distance Versus Amplitude.

NOTE

The important thing to remember is, wide variations in amplitude from discontinuities can occur when inspecting in the near field.

It is always best to compare discontinuity signals with signals from reference standards, such as flat-bottom holes having the same metal travel distance as the discontinuity. A typical curve showing the amplitude response versus distance from the transducer face is shown in Figure 5-9.

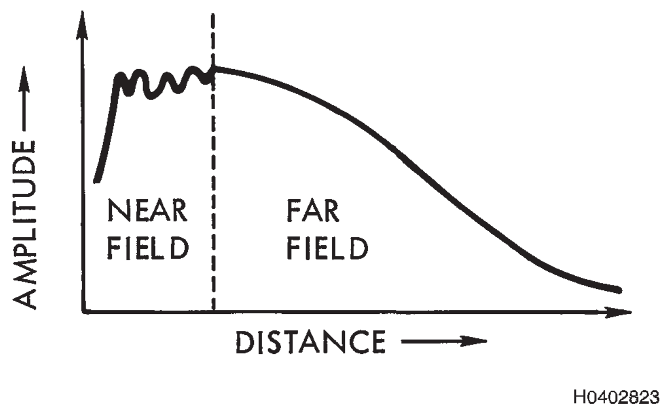


Figure 5-9. Amplitude Response Curve of Typical Transducer

5.2.6.5 Beam Spread. In the near field, the sound beam essentially propagates straight out from the face of the transducer. In the far field, the sound beam spreads outward and decreases in intensity with increasing distance from the transducer face as shown in Figure 5-9. Beam spread is important to consider because in certain inspection applications the spreading sound beam may reflect off of walls or edges, causing erroneous or confusing signals on the A-scan presentation (Figure 5-10). The formula for calculating the half-angle of the beam spread is located in paragraph 5.7.6.

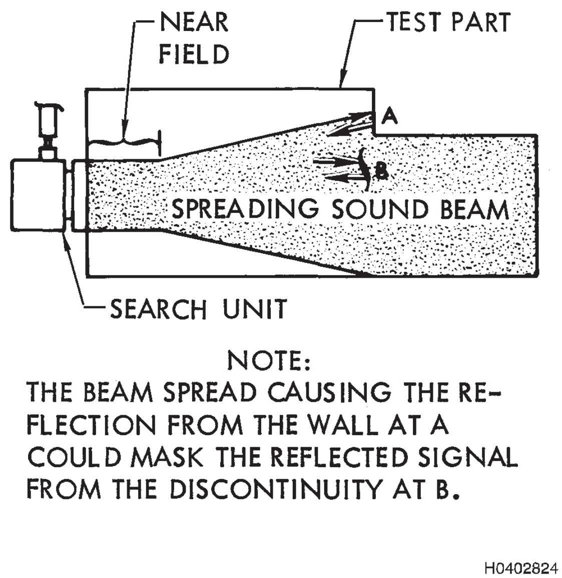


Figure 5-10. Example of Beam Spread Causing Confusing Signals

5.2.6.5.1 In addition to the main sound beam pattern discussed above, there is also a small amount of side lobe energy (Figure 5-11). Some of the effects of this side lobe energy are discussed in paragraph 5.5.3.1. Another adverse affect of side lobes, is a reduction in the efficiency of the transducer. Due to the interference created by the side lobes, the actual useable width of a sound beam near the face of the transducer is less than the actual width of the piezoelectric element (Figure 5-11).

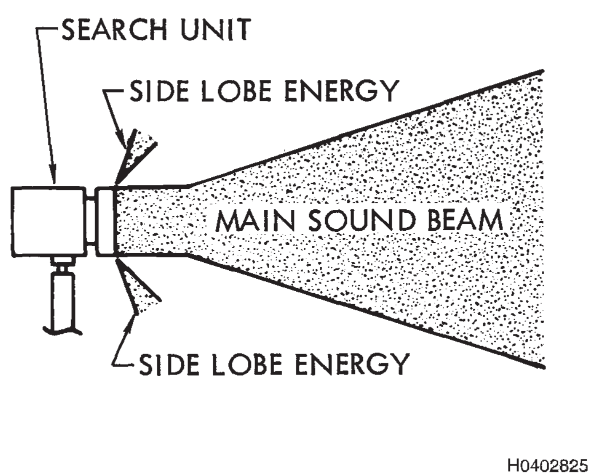


Figure 5-11. Main Sound Beam and Side Lobe Energy

5.2.6.6 Beam Intensity. Beam intensity is the sound wave energy transmitted through a unit cross-sectional area of the beam. The intensity is proportional to the square of the acoustic pressure exerted in the material by the sound wave. The acoustic pressure is directly related to the amplitude of the material particle vibrations caused by the sound wave. Transducer elements sense the acoustic pressure of the reflected sound wave and convert it to an electrical voltage. Ultrasonic instrument receiver-amplifier circuits receive the input voltage from the transducer and produce an output voltage value proportional to the intensity of the reflected sound. This output voltage is typically displayed on the instrument display as an A-scan signal.

5.2.6.7 Attenuation. Attenuation is the loss in acoustic energy that occurs between any two points of travel. The amount of loss is measured in decibels, but direct measurement of material attenuation can be very difficult. Beam attenuation occurs due to many factors that include absorption, scattering, diffraction, beam spread, geometry of the part, or other material characteristics.

SECTION III ULTRASONIC INSPECTION EQUIPMENT AND MATERIALS

5.3 INTRODUCTION.

5.3.1 Ultrasonic Instruments.

5.3.1.1 General Description. Ultrasonic equipment performs the functions of generating, receiving, and displaying pulses of electrical energy, which have been converted to and from pulses of ultrasonic energy by a transducer attached to an instrument. All portable ultrasonic equipment consists of a power supply, a clock circuit, a pulser, a sweep circuit, a transducer, a receiver-amplifier circuit, and an instrument display. By properly adjusting an instrument an operator can measure the amplitude of displayed pulse signals and determine the time/distance relationships of the received signals. Detailed instructions for operation of individual models SHALL be obtained by consulting the operating and maintenance manual for the specific instrument being used.

5.3.1.2 Scanning Equipment. Many applications lend themselves to either automated, or semi-automated scanning techniques. Most scanning applications are computer controlled and can result in A-scan, B-scan, or C-scan outputs. Scanning equipment ensures full coverage of the inspection zone and can be accomplished at resolutions unobtainable by manual scanning. Scanning mechanisms come in many levels of sophistication. Two-axis scanners can be manually manipulated or computer-automated to any extent. Large gantry-based immersion or “squirter” systems have up to 16 or more axes and offer full-contour scanning of complex shapes.

5.3.1.3 Physical Characteristics of Instrument Controls. The physical nature of the instrument controls varies with the type and age of the instrument. Older instruments have rotary knobs for fine adjustments, slide switches for coarse adjustments, and screwdriver rotary controls for infrequent adjustments, of waveform position and visibility. Newer instruments have push buttons or a sealed membrane keypad, both to select the desired control from a displayed menu and to make the respective adjustments. Alternatively, some menu driven instruments have a single rotary (“smart”) knob for making adjustments after a control has been selected from the menu.

5.3.1.4 Waveform Display Controls. An ultrasonic instrument may have one of several types of waveform displays; traditional cathode ray tube (CRT), liquid crystal display (LCD), or electroluminescent display (EL). Controls affecting the waveform display are discussed below.

5.3.1.4.1 Scale Illumination.

CAUTION

If the intensity of a CRT is allowed to remain at a high level for long periods, it is possible to permanently burn the display.

The horizontal and vertical scales are illuminated in various ways. On some instruments, the scales are scribed on the faceplate and cannot be illuminated. On a CRT, the brightness control for the scales may be integrated with a rotary power switch or a separate control. Other types of display may simply have an on/off switch for illumination control.

5.3.1.4.2 Waveform Positioning Controls. The events in an ultrasonic inspection are related to time referenced to the pulses produced by the instrument. Pulses or signals will be represented along a horizontal line (typically called the sweep or baseline) at the bottom of the screen. Time starts at the left end of the sweep and progresses to the right. The sweep, included within the “frame” Figure 5-12), is a visual presentation of a portion of the time base. The following typical controls are used to properly align the baseline on the display screen. These two adjustments are generally not required on digital display flaw detectors.

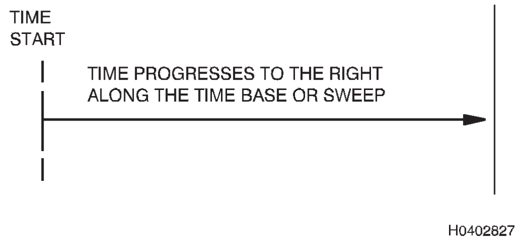


Figure 5-12. Time Base

5.3.1.4.2.1 Horizontal Position. The horizontal position control should be adjusted so that the horizontal baseline (sweep) begins at the left edge of the display.

5.3.1.4.2.2 Vertical Position. The vertical position control should be adjusted so the horizontal time base is at zero position of the vertical scale.

5.3.1.4.3 Type of Waveforms.

5.3.1.4.3.1 Radio-Frequency (RF) Display, (Non-rectified). This type of waveform has the baseline at 50-percent of full screen height and shows the full waveform with both the positive and negative peaks. This type of waveform contains all of the signal information and is often used during procedure development to decide which waveform display is best suited for a particular inspection.

5.3.1.4.3.2 Full-Wave (FW) (Rectified Video Display). This type of waveform shows the positive peaks and the negative peaks, but the negative peaks are reversed and made positive.

5.3.1.4.3.3 Positive Half-Wave (HW+ or HWP) (Rectified Video Display).This type shows only the positive peaks.

5.3.1.4.3.4 Negative Half-Wave (HW- or HWN) (Rectified Video Display).This type shows only the negative peaks.

5.3.1.4.4 Video Filtering. Some instruments provide varying degrees of filtering of the rectified waveforms. Filtering smooths out the waveform, but some loss of information occurs. With minimum filtering, the presentation has greater resolution and signal definition. Video filtering MAY affect the vertical linearity of the instrument.

5.3.1.4.5 Sweep Delay. The sweep delay control determines what part of the time base is viewed on the display. An area circled to frame the portion of the time base that an inspector wants to view is shown (Figure 5-13) on the instrument display. Adjustments to the sweep delay move the frame to the desired portion of the time base, that is, sweep delay delays the start of the sweep with respect to the start of the time base.

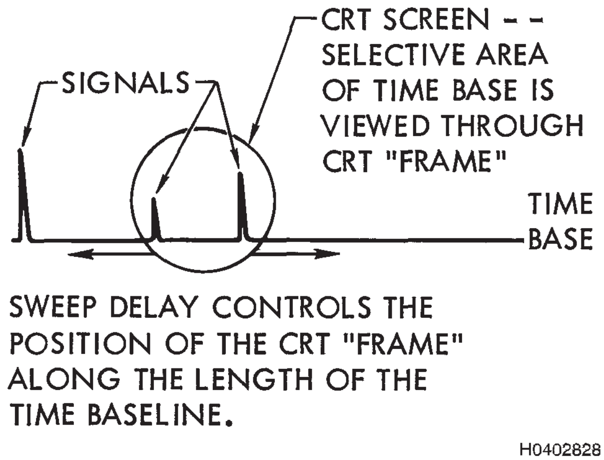


Figure 5-13. Relationship of CRT Sweep to Time Base

5.3.1.4.5.1 To see how the sweep delay works, consider the inspection shown in Figure 5-14. Under certain control settings (e.g., immersion testing) (paragraph 5.4.2.1.1.2), an instrument with a CRT might have a sweep appear as in Figure 5-15 showing only the front surface and discontinuity signals. By adjusting the sweep delay to move the "frame" to the right along the time base, the display shown in Figure 5-16 is obtained.

NOTE

The front surface signal now appears on the far left, and the back surface signal can now be viewed also. The distance between the front surface and the discontinuity signals has not changed from Figure 5-15.

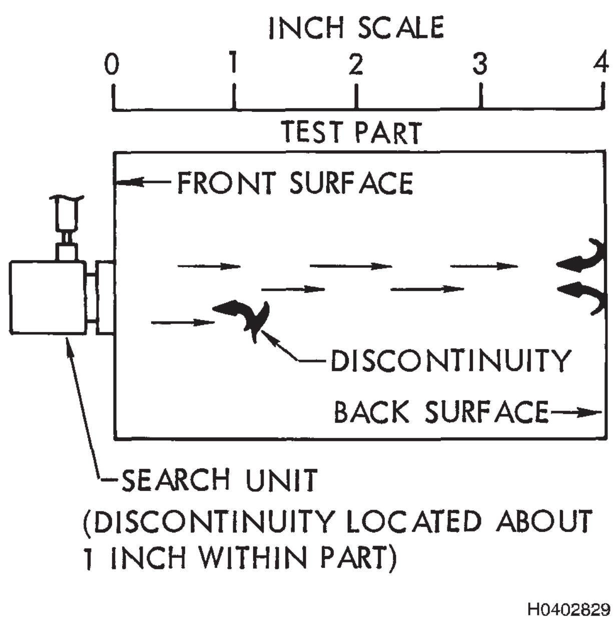


Figure 5-14. Ultrasonic Contact Inspection

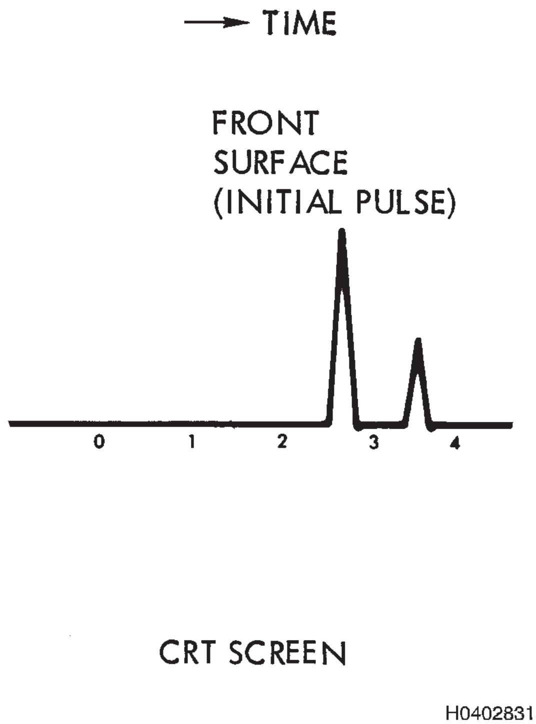


Figure 5-15. Display Screen Before Adjusting Sweep Delay

5.3.1.4.6 Sweep Length/Range. The sweep length (range) control determines how much time/distance is represented by the sweep on the display. If the range is adjusted to decrease the time/distance represented, the spacing between the signals will increase. The range control is used to calibrate the time base to specific distances for measurement purposes. In Figure 5-16, if the sweep length/range is adjusted to decrease the time/distance represented (the sweep length/range), the spacing between the signals will increase, as seen in Figure 5-17.

NOTE

The front surface signal did not move; only the distances between the front surface signal and the other signals increased.

5.3.1.4.6.1 Referring back to Figure 5-14, the 4-inch length of the test part and the 1-inch depth of the discontinuity are represented by the signals in Figure 5-17 at "4" and "1" respectively. In other words, the sweep length/range control is used to calibrate the time base to the test part using the horizontal scale on the display.

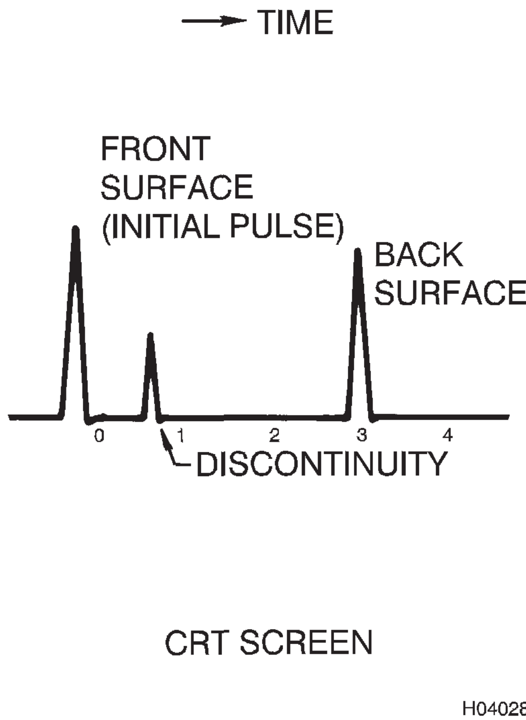


Figure 5-16. Display Screen After Adjusting Sweep Delay

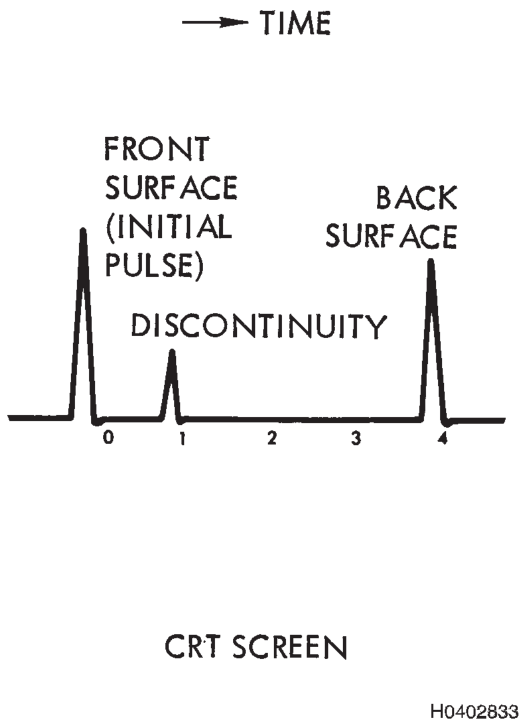


Figure 5-17. Effect of Sweep Length on CRT Display

5.3.1.4.7 Zero Offset (Zero). A zero offset (zero) control is a fine-delay control used to compensate for transducer face-plate wear. In angle beam inspections with a wedge, or straight beam inspections with a delay line, this control can be used to compensate for the distance the sound beam travels in a plastic wedge or delay line. Essentially, it allows the inspector to set "time zero" for electronic distance calculations to the exact instant the sound pulse enters the part.

5.3.1.4.8 Velocity. The velocity control allows the inspector to enter the material velocity of the material under inspection. By entering the velocity in conjunction with proper range and delay settings, the horizontal scale of the display will be automatically calibrated to provide the depth of any discontinuity detected in that particular test part.

5.3.1.5 Pulser Controls. When electronically triggered by the clock circuit, the pulser sends a high voltage spike to the transducer producing the initial pulse. Adjustments of the following pulser controls (if permitted by procedure) can be made to more clearly define the discontinuity indications.

5.3.1.5.1 Pulse Repetition Rate (Rep Rate or PRR). The pulse repetition rate is the actual number of trigger pulses produced per second and is controlled by the clock circuit. Typical rates are 300 to 2000 pulses per second. Typically, the higher the rate, the faster the scanning speed can be while still maintaining the required sensitivity. The maximum rep rate is the rate beyond which unattenuated echo signals occur on the display from an earlier pulse; this is called "wrap around" or "ghost" signals. These signals can be recognized by the occurrence of unexplained signals on the display which disappear if the rep rate is decreased while the transducer is held motionless on the test part. Some instruments include an automatic override to set the rep rate at a reduced value if the inspector tries to set it manually above a value compatible with the sweep settings.

5.3.1.5.2 Pulse Controls. On some instruments, the following controls are automatically set to default values when a new setup is initiated or when other interactive controls are adjusted. Adjustments of the following controls (if permitted) MAY be made to more clearly define the discontinuity indications.

NOTE

Minimum pulse length, (maximum damping) is obtained with the load resistance as small as possible for the circuitry. Load resistance selections may range from 16 ohms for maximum damping to 500 ohms for maximum pulse length (minimum damping).

5.3.1.5.2.1 Pulse Length (Damping). The pulse length (damping) control is used to adjust the time duration of the high-voltage spike pulse applied to the transducer. A higher damping value (shorter pulse length) provides the best near-surface resolution. A lower damping value (longer pulse duration) may provide more penetrating power for highly attenuative materials, such as rubber and concrete. The length of the initial pulse SHOULD be kept to a minimum, and increased only to gain signal strength when required; excessive pulse length can obscure signals from discontinuities close to the inspection surface (poor near-surface resolution).

5.3.1.5.2.2 Pulse Voltage. This control determines the amplitude of the generated initial pulse. Some instruments have incremental voltage adjustments; for example, from 40 to 400-volts in 5-volt increments. Other instruments have adjustments for only low, medium, or high voltages.

5.3.1.5.2.3 Pulse Width. Some instruments generate a square pulse as opposed to a spike pulse. The pulse width control sets the width of the square pulse, usually in nanoseconds. The effect of the pulse width is similar to the damping control, although the electronic nature of each is different.

5.3.1.6 Receiver Controls.

5.3.1.6.1 Receiver Gain. The gain control is used to adjust the amplitude (height) of signals on the waveform display. A positive increase in the gain control will increase the amplitude of the signals; however, on a few instruments the control is actually an attenuation control, with which a positive adjustment will decrease the amplitude of the signals. Some instruments will have both gain and attenuation controls. On most instruments, the gain control is calibrated in terms of the decibel (dB). The decibel is used to express the relationship between two signal amplitudes:

$$dB = 20 \log_{10}(A_2/A_1)$$

where:
A_2 and A_1 are the two amplitudes that are being compared.

5.3.1.6.1.1 For every 6 dB increase, the amplitude of a signal doubles. Thus, with an 18 dB increase, a signal would have eight times the original amplitude. Conversely, the signal amplitude is cut in half with a decrease of 6 dB. The relationship of dB to the amplitude ratio is shown in Figure 5-18.

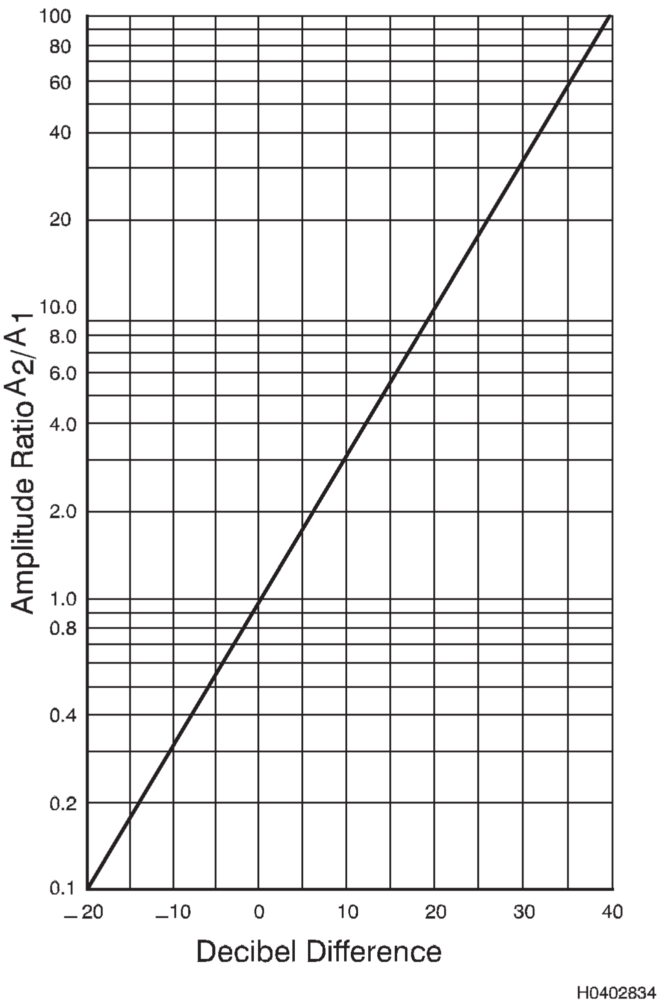


Figure 5-18. Decibel-to-Amplitude-Ratio Conversion Chart

5.3.1.6.2 Reject.

CAUTION

The REJECT control SHALL NOT be set at or above the rejectable signal threshold because this will cause defects to be missed.

The reject control is used to attenuate irrelevant low-level signals and noise on the waveform display. This often permits easier interpretation of echo signals, but can also obscure wanted signals if applied inappropriately. Most new instruments have linear reject controls which eliminate the low-level signals without affecting the amplitude of the relevant echo signals. The effect of the linear reject control is illustrated in Figure 5-19.

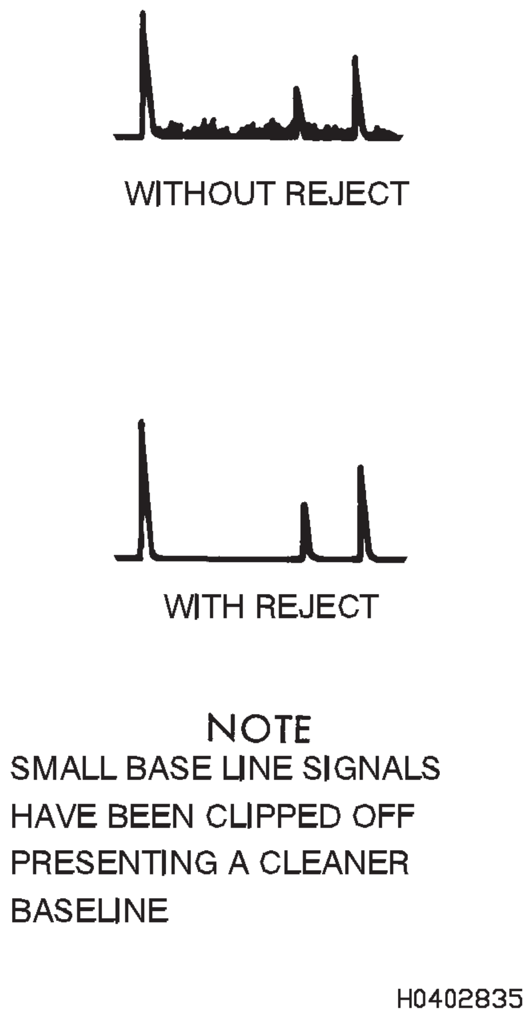


Figure 5-19. Reject Control

5.3.1.6.3 Frequency. The Frequency control allows the inspector to select the frequency corresponding to a transducer or to select the broadband mode to cover all frequencies. The selection that gives the best echo signal is normally used.

5.3.1.6.4 Single/Dual Transducer. This control configures the transducer-cable receptacles for single-element transducer, dual-element transducer, or two separate transducers (through-transmission) inspection. The Dual position of the control is used for both dual-element-transducer and two-transducer inspections; in these cases, some instruments specify one receptacle as transmitter and the other as receiver. For single-element-transducer inspections, only one receptacle is used. Consult the instrument manual or procedure for the appropriate use of the connectors.

5.3.1.6.5 Electronic Distance Amplitude Correction (DAC). Distance Amplitude Correction (DAC) MAY also be called STC (Sensitivity Time Control), TCG (Time Corrected Gain), TVG (Time Varied Gain). DAC electronically compensates for material attenuation. Attenuation typically results in decreasing amplitude echoes from equal-size reflectors located at increasing travel distances from the transducer. After DAC is applied over a particular thickness, all the echoes from reflectors of equal size and in the same orientation within that thickness, will be displayed at the same amplitude.

5.3.1.7 Flaw Gates. A gate is an electronic feature that allows an inspector to monitor for discontinuities within specific zones of the test part. A gate appears on the display as a short horizontal sweep segment above the baseline. The gate can be adjusted so any signal that appears within the limits of the gate will energize an audible or visual alarm alerting the inspector to a possible flaw that needs to be investigated further. Controls for the gate on the display are as follows.

5.3.1.7.1 Gate Start. This control is used to adjust the location of the leading edge of the gate on the display.

5.3.1.7.2 Gate Width/Length. This control is used to adjust the width of the gate or the location of the trailing edge of the gate.

5.3.1.7.3 Threshold/Alarm Level. This control adjusts the vertical position of the gate trigger level (accept/reject level). A positive gate is defined when a signal triggers the gate as it exceeds the threshold level. A negative gate is defined when a signal triggers the gate as it falls below the threshold level. Often referred to as "Gate Logic" on ultrasonic units, "Positive Logic" is when the alarm is triggered as the signal exceeds the gate and "Negative Logic" is when the alarm is triggered as the signal falls below the gate. Only signals that exceed the level of the gate cause an alarm or a record to be made.

5.3.2 Transducers.

CAUTION

Transducers are fragile and SHALL be handled with care. Sharp blows, caused by dropping or banging a transducer against a surface, could cause extensive damage.

5.3.2.1 General Description. Transducers serve to convert electrical energy received from the ultrasonic instrument pulser into acoustic energy through the use of piezoelectric elements. The acoustic energy enters the test piece and returns to the transducer where it is converted back to electrical energy and returned to the ultrasonic instrument for display. Transducers are available in a great variety of shapes and sizes.

5.3.2.2 Transducer Construction. The schematic in Figure 5-20 shows the basic parts of a typical straight beam transducer used for contact inspection, while Figure 5-21 schematically shows an angle beam transducer. The backing material, shown in Figure 5-20, serves to damp the ringing of the transducer element after it is excited. This affects the resolution of an inspection as explained in paragraph 5.3.2.4.2. The plastic wedge, serves to transmit longitudinal waves to the test part surface where mode conversion occurs. Refracted longitudinal, shear, or surface waves (depending on the angle of the plastic wedge) are generated in the test part.

5.3.2.3 Types of Contact Transducers. Contact transducers are typically hand-held and manually scanned in direct contact with the inspection piece. A couplant material is required to ensure sound transmission between the transducer and the test piece.

5.3.2.3.1 Straight Beam. Straight beam (also known as "0 degree" or "zero degree") transducers are used to launch longitudinal sound beams into a test piece and can be used singularly in a pulse-echo scenario or in tandem for through-transmission or pitch-catch techniques. Typically straight beam transducers are used in a pluse-echo mode detecting laminar discontinuities with surfaces lying parallel with the inspection surface. The basic parts of a typical straight beam transducer used for contact inspection are schematically shown in Figure 5-20.

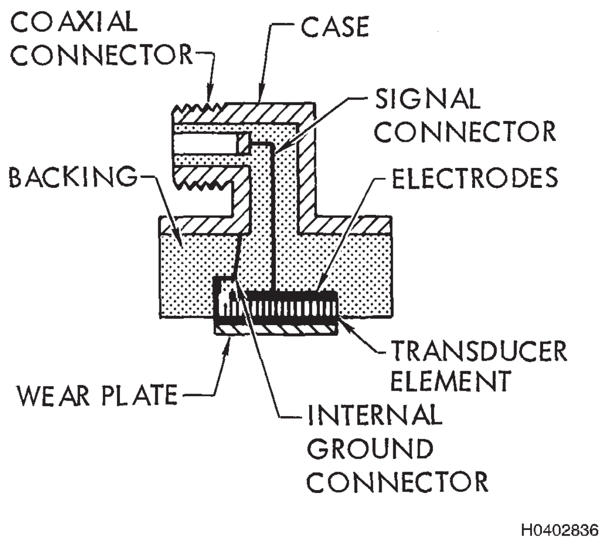


Figure 5-20. Straight Beam Contact Transducer

5.3.2.3.2 Angle Beam. Angle beam transducers are used to launch shear wave sound beams into a test piece and are typically used in a pulse-echo scenario. Typical uses for angle beam transducers include tube, plate, or pipe welds or anywhere there is a need to launch a sound wave at other than parallel to the test piece surface. An angle beam transducer is schematically shown in Figure 5-21. The plastic wedge serves to transmit longitudinal waves to the test part surface where mode conversion occurs. Refracted longitudinal, shear, or surface waves (depending on the angle of the plastic wedge) are generated in the test part.

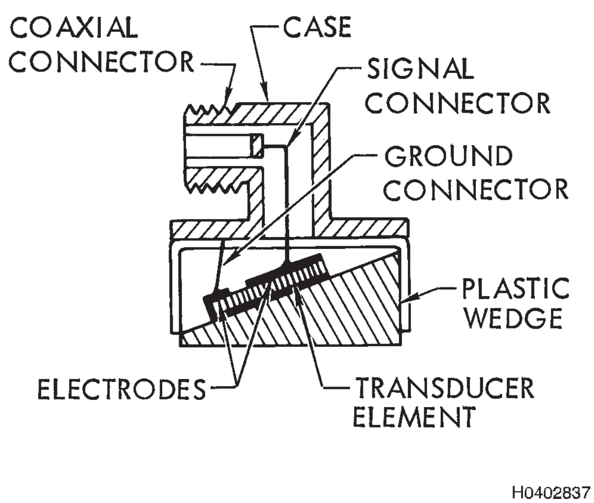


Figure 5-21. Angle Beam Contact Transducers

5.3.2.4 Transducer Sensitivity and Resolution.

5.3.2.4.1 Sensitivity. Sensitivity is the ability of an inspection system to detect small discontinuities. It is generally rated by the ability to detect a specified size and depth of a flat-bottom hole in a standard test block. Sensitivity is unique to each combination of transducer and test instrument. The ability to detect small discontinuities is typically increased by using a higher frequency (shorter wavelength) although penetrating power is sacrificed.

5.3.2.4.2 Resolution. Resolution refers to the ability of an inspection system to separate (distinguish) signals from two interfaces close together in depth. An example of two such signals is the front surface signal and the signal from a small discontinuity just beneath the surface. The damping or backing material affects the time required for the transducer to stop “ringing” after being excited by a pulse from the test instrument. Low damping causes high “ringing” resulting in a wide, high-amplitude front surface signal. This would cause a long dead zone and a subsequent loss of resolution. Generally, resolution improves with a higher frequency.

5.3.2.5 Transducer Shape and Size. The variety of sizes and configurations of transducers that can be used is almost endless. Transducer faces can be round or rectangular. Transducers 1/8-inch diameter and smaller have been used.

5.3.2.6 Dual Transducers. Dual transducers are used primarily in applications where good near-surface resolution is required. Ultrasonic thickness measurement instruments commonly use dual transducers. The operation of a typical dual transducer is shown in Figure 5-22. The spaces under the transducer elements are usually filled with plastic material that serves as a delay line. Thus, the initial pulse does not interfere with any echoes from the near surface of the test piece. Dual transducers are also used in angle beam inspection. Two types of angle beam dual transducers are shown in Figure 5-23.

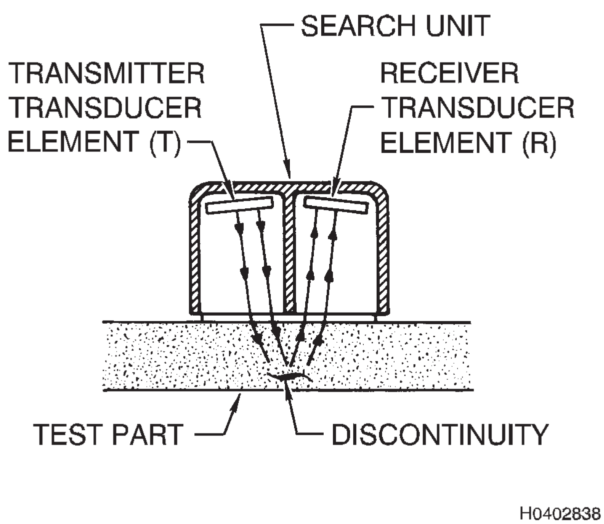


Figure 5-22. Dual Transducer Operation

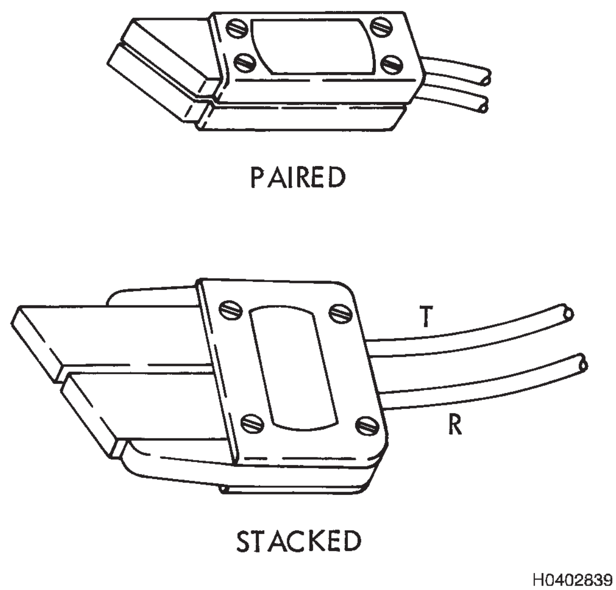


Figure 5-23. Angle Beam Dual Transducers

5.3.2.7 Wear Faces. Transducers are often fabricated with removable plastic or rubber wear faces. These faces improve coupling on rough surfaces and prevent wear of the transducer face; however, the flexible wear faces reduce the amount of power available from the transducer.

5.3.2.8 Delay Lines. A transducer may have a solid, or a fluid delay line. Delay lines move the part surface out of the dead zone, thereby improving near-surface resolution. Because of the increased resolution, delay lines are used extensively for thickness measurements and other applications that require a high degree of resolution.

5.3.2.8.1 Solid Delay Line. A solid delay line may be an integral part of the transducer or may be removable. An integral delay line is bonded to the transducer element. A removable delay line requires a couplant between it and the transducer face. Various lengths of removable delay lines can be interchanged and can be replaced when worn.

5.3.2.8.2 Fluid Delay Line. Some transducers are equipped with water delay columns. The water column also permits the use of focused transducers. The delay line can either have an open bottom requiring a rapid flow of water to maintain coupling, or it can be equipped with a thin membrane at the bottom. This form is common in large automated scanning systems. The membrane is usually punctured in the middle to provide a slow flow of water for coupling. Water delay lines with flowing water are also called “bubblers” or “squirters.” A variety of sizes are used. Fluid delay lines provide the same advantages in resolution as solid delay lines.

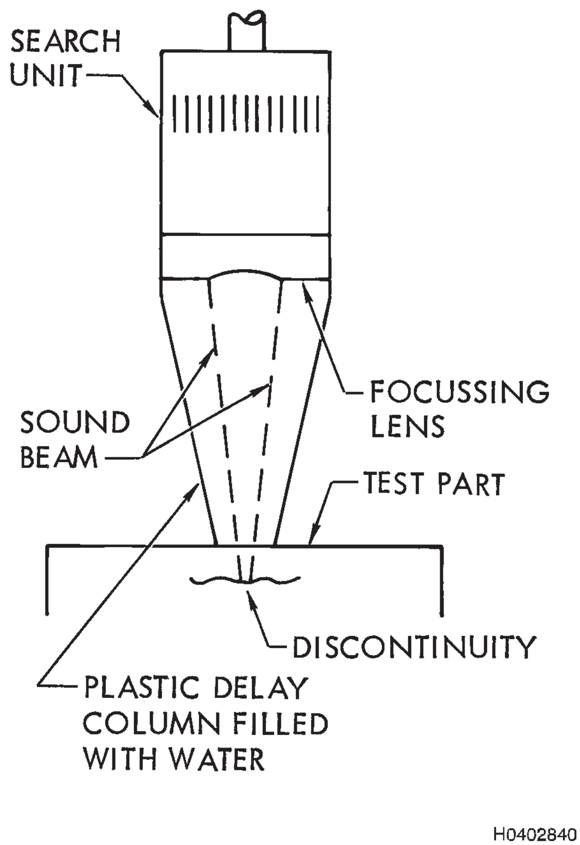


Figure 5-24. Water Delay Column Transducers

5.3.3 Specialized Transducers.

5.3.3.1 Focused Sound Beams. On some immersion inspections (paragraph 5.4.2.1.1.2) or special contact tests with a water delay column, a focused sound beam is used (Figure 5-24). As shown in Figure 5-25, the focusing is produced by using a transducer containing a plastic acoustic lens on the face of the transducer element. The acoustic lens causes the sound beam to converge as the sound travels away from the transducer. Due to refraction at the plastic-water interface, a peak in amplitude is obtained at the focal point. The amplitude then decreases rapidly on each side of this point. This type of transducer has a high sensitivity for discontinuities located at the focal point distance due to the concentration of energy at this focal point, but the depth of material inspected in any one scan is limited. Beam shaping, which “tucks in” the side lobes can also be accomplished by using an acoustic lens without creating a focused transducer.

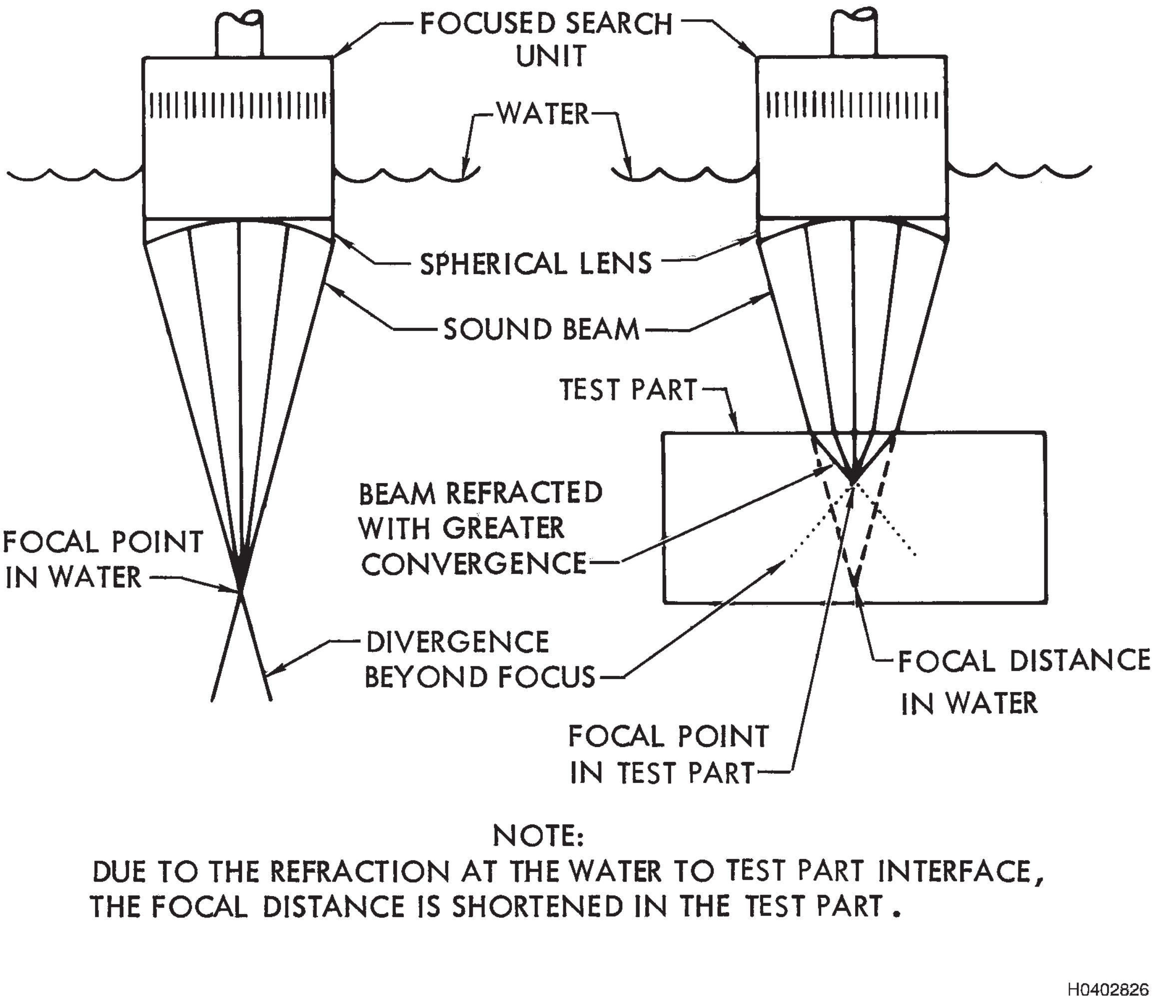


Figure 5-25. Focused Sound Beams

5.3.3.2 Wheel Transducers. A wheel search unit operates much like an immersion probe and consists of a flexible tire filled with liquid and containing one or more transducer elements. As shown in Figure 5-26, sound is transmitted through the liquid, the tire, and into the part through a thin couplant film between the tire and the part. Wheel search units can be used for straight beam and angle beam applications and are most advantageous for large area scanning of plate or other flat stock material.

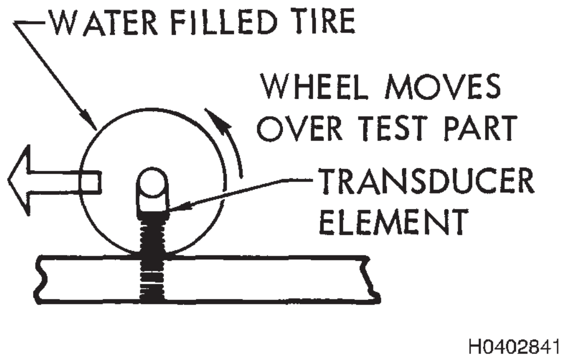


Figure 5-26. Wheel Transducer

5.3.3.3 Paint Brush or Array Probes. Large-area inspections can sometimes be made easier by use of a paint-brush probe. These probes are made up of an array of transducers or crystals in an extended length that allows a wide inspection area to be covered with one scan. The crystals that make up the array must be matched such that the beam intensity does not vary greatly over the length of the probe.

5.3.3.4 Collimators. Transducers can be equipped with collimators to reduce the size of the sound beam entering the test part. The collimator may be a solid cone (usually acrylic plastic) bonded to the face of the transducer. This type of collimator reduces the diameter of the sound beam entering the test part to the diameter of the tip of the cone. The cone also acts as a delay line and can result in better near surface resolution. However, this type of collimator reduces the energy entering the test part. Hollow cylindrical collimators MAY also be used in immersion inspections in which the collimator is attached to an immersion transducer to control the beam shape.

5.3.4 Wedges and Shoes. Wedges and shoes are used to adapt transducers for angle beam and surface wave inspections and for inspecting parts with curved surfaces. If flat probes are used on convex surfaces, the ultrasonic energy transmitted into the part is drastically reduced, because only the center of the transducer makes good contact with the part. Flat transducers of small size (1/4-inch or less diameter or width) can be used in some cases on convex surfaces down to 1.5-inch radius. However, loss of power results due to the smaller contact area. Inspections performed with flat-faced transducers on curved surfaces will be hindered by the tendency of the transducer to rock (Figure 5-27). This varies the angle of the incident and refracted sound beam and causes problems in interpretation.

5.3.4.1 Guidelines for Use of Curved Wedges and Shoes.

5.3.4.1.1 Wedges and shoes SHALL be used on all convex surfaces with a radius of curvature of 1.5-inches or less. They SHOULD be used on all convex surfaces with a radius of curvature between 1.5 and 4.0-inches.

5.3.4.1.2 Wedges and shoes SHALL be used on all concave surfaces with a radius of curvature or less than 4-inches.

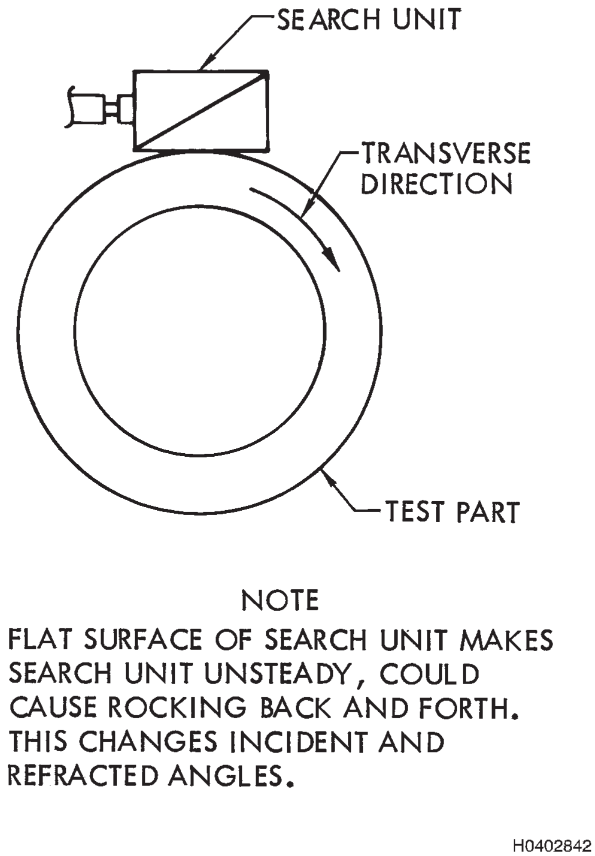


Figure 5-27. Angle Beam Inspection of Curved Surface Using Flat Transducer

5.3.4.2 Design and Fabrication of Wedges and Shoes.

CAUTION

- Field units SHALL NOT manufacture shoes and/or wedges unless specifically directed by TO or other approved written procedure. If authorized, the procedure SHALL provide material requirements and detailed dimensional requirements.

- Excessive heat, generated during fabrication (machining or sanding), of acrylic plastic wedges and delay elements, MAY significantly increase the attenuation of ultrasound in this material.

5.3.4.2.1 Plastic wedges and shoes can be fabricated from Lucite, polystyrene, or other acrylic (Item Grade C plastic of Federal Specification L-P-391) plastics. Some plastics will scatter ultrasonic energy; so before using a plastic, a sample SHALL be checked to ensure sound can be adequately transmitted through the material. The sample SHALL be at least as thick as the wedge or shoe to be fabricated. Check the sample using a straight beam (paragraph 5.3.2.3.1) inspection and the highest frequency that will be used with the completed wedge or shoe, and note the back reflection signal. If a strong back reflection (at least 100-percent saturation) cannot be obtained with a reasonable gain setting, new material SHALL be procured and checked.

5.3.4.2.2 Angle beam wedges MAY be fabricated according to Figure 5-28 or Figure 5-30. The wedge in Figure 5-28 has provisions built in for mounting the straight-beam transducer, while the wedge in Figure 5-30 requires a coupling fixture Figure 5-29 for mounting the straight-beam transducer. Similar fixtures MAY be procured or locally manufactured. The incident angle, “Φ_1”, for each wedge SHALL be determined by using Snell’s law and the respective velocities of the wedge, test material and the refracted angle, “Φ_2”, required by the inspection procedure. Values for “Φ_1”, calculated for listed refracted angles in materials are contained in Table 5-8.

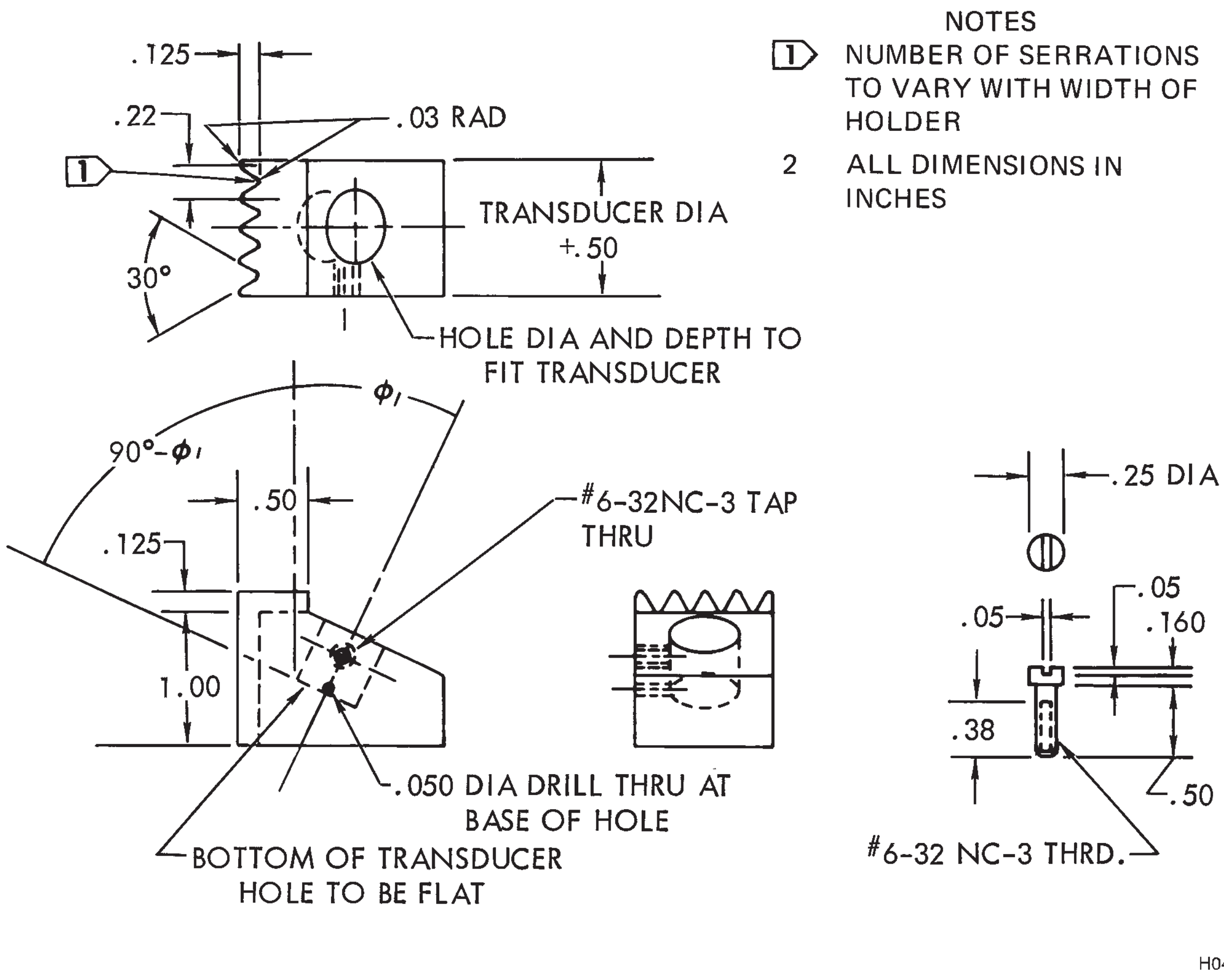


Figure 5-28. Angle Beam Wedge With Hole for Mounting Transducer

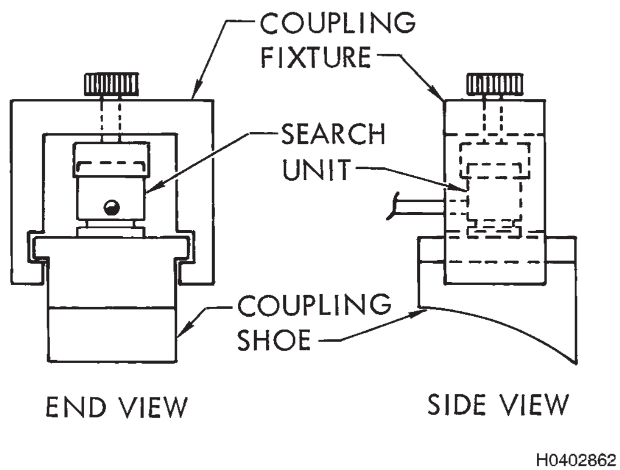


Figure 5-29. Use of a Coupling Fixture to Hold Transducer on Shoe

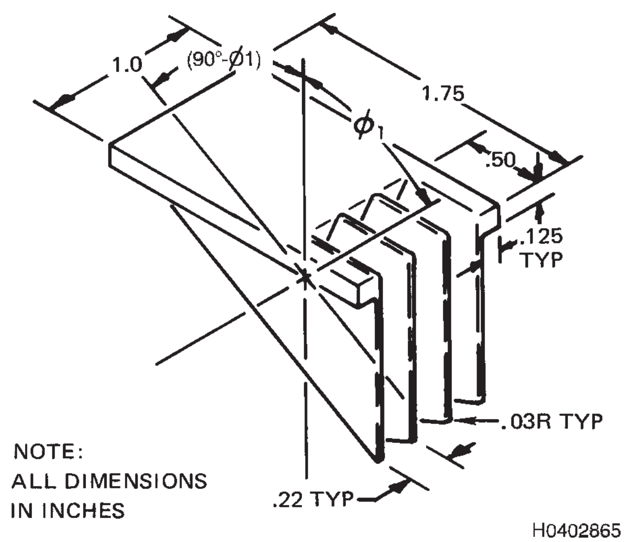


Figure 5-30. Angle Beam Wedge Requiring a Coupling Fixture

5.3.4.2.3 Notice the serrations on the wedges in Figure 5-28 and Figure 5-30. These serve to dampen and scatter reflected sound that does not initially enter the test part. The serrations, therefore, reduce false signals.

5.3.4.2.4 The configurations of the wedges in Figure 5-28 and Figure 5-30 MAY be modified as required to take care of special geometry situations. In all cases, wedges SHALL be fabricated to provide the proper refracted angle for the desired mode of vibration. In addition, they SHALL provide for transmission of sound into the test part at the locations required to cover the areas of suspected flaws.

5.3.4.2.5 Look at Figure 5-29 to see how the coupling fixture is used with the wedge in Figure 5-30. A few drops of couplant material is needed between the transducer and any wedge to ensure good sound transmission.

5.3.4.2.6 A typical shoe used for curved surfaces is shown in Figure 5-31. This example MAY be used as a guideline for fabrication of shoes for curved surfaces. Dimensions MAY be changed to accommodate the specific part to be inspected.

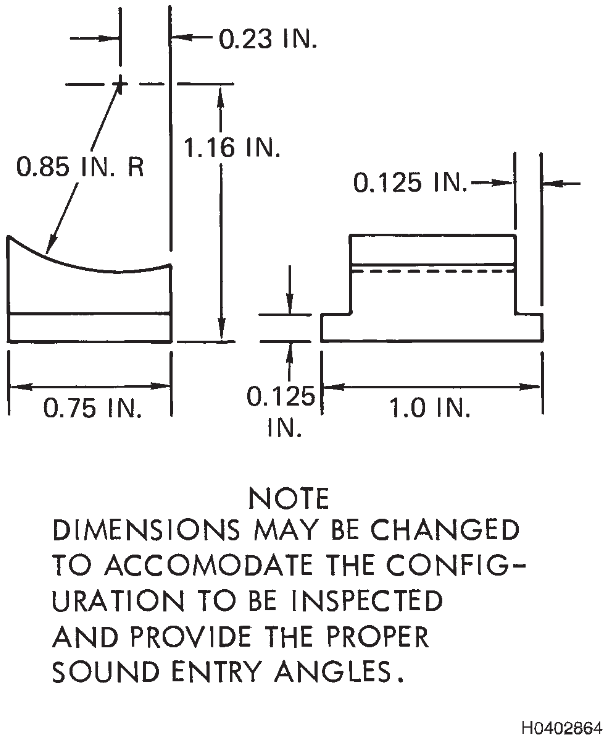


Figure 5-31. Typical Curved Surface

5.3.4.2.7 Although shoes for curved surfaces are usually fabricated from acrylic plastic, sometimes shoes are fabricated from the same material as the test part. When using shoes of the same test part material, the sound beam travels straight into the test part from the shoe; refraction does not occur.

5.3.4.2.8 The radius of curvature of each shoe SHOULD match the radius of curvature of the test part. Small changes in the curvature of the shoe can be accomplished on the test part by inserting number 400 or finer grit sandpaper between the shoe and the test part, and then sliding the shoe across the sandpaper. Major shaping of a shoe SHOULD be done in a machine shop, because the shoe cannot be held steady enough by hand.

5.3.4.2.9 In some cases, when using plastic shoes for angle beam inspection on curved surfaces, the portion of the sound beam (away from the beam center) could produce unwanted longitudinal and/or surface waves as shown in Figure 5-34. This effect increases with decreasing radii of curvature. Also, when using large angles (70° or larger) for inspecting cylindrical shapes in the longitudinal direction, interfering surface waves could be generated. These waves leave the shoe on both sides at an angle to the longitudinal direction (Figure 5-32). In these cases, it is not desirable to adapt the shoe to a close fit with the part. The shoe SHOULD be made so only the central portion of the beam centers the test part. As an option, slots MAY be cut in the bottom surface of the shoe. The slots SHOULD be oriented perpendicular to the direction of propagation of the unwanted surface waves and located away from the exiting beam center (Figure 5-33). The dimensions of the slots SHOULD be about 1/8-inch wide by 1/8-inch deep.

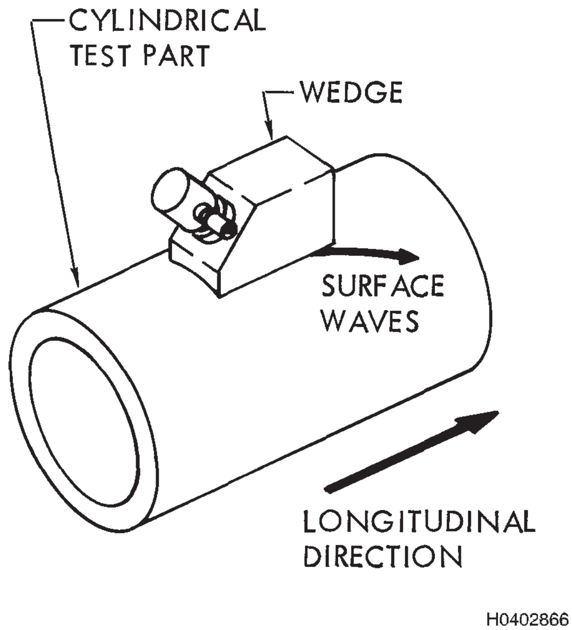


Figure 5-32. Generation of Unwanted Surface Waves During Inspection of Cylindrical Part in the Longitudinal Direction

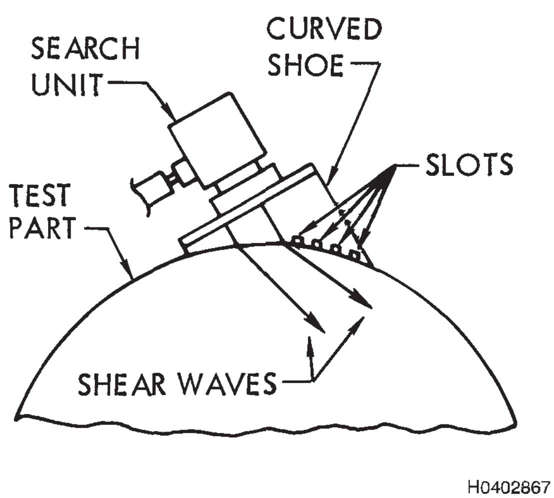


Figure 5-33. Slots in Shoe to Eliminate Unwanted Surface Waves

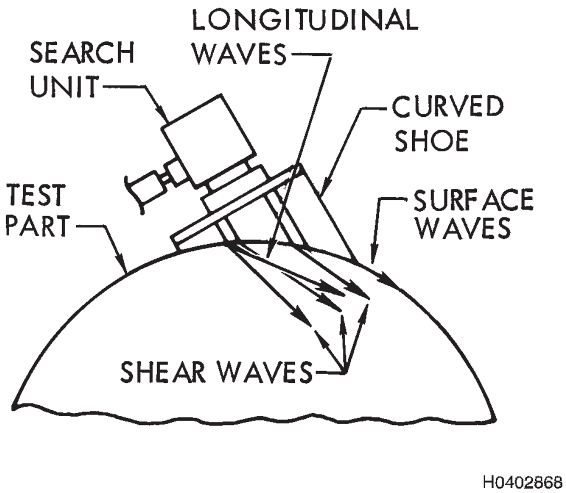


Figure 5-34. Generation of Unwanted Longitudinal and Surface Waves on Curved Surface

NOTE

Unwanted surface waves can be detected by noting additional unexpected signals on the waveform display. If these signals can be damped and traced to their source using an oil-wetted finger, as explained in (see paragraph 5.4.6.4.3, step c) unwanted surface waves are being generated.

5.3.4.2.10 When designing shoes for curved surfaces, the sound beam path in the shoe and the test part SHALL be considered in order to ensure coverage of the area of interest within the test part. Generally, the sound beam path in the shoe can be considered to be a straight projection of the transducer face; in almost all cases the sound travel in the shoes will be in the near field and characterized by no beam spread. The beam path in the part can be obtained by using Snell's Law (paragraph 5.2.4.1) and (Figure 5-35) to determine the refracted angle at various points across the sound beam where it enters the test part surface.

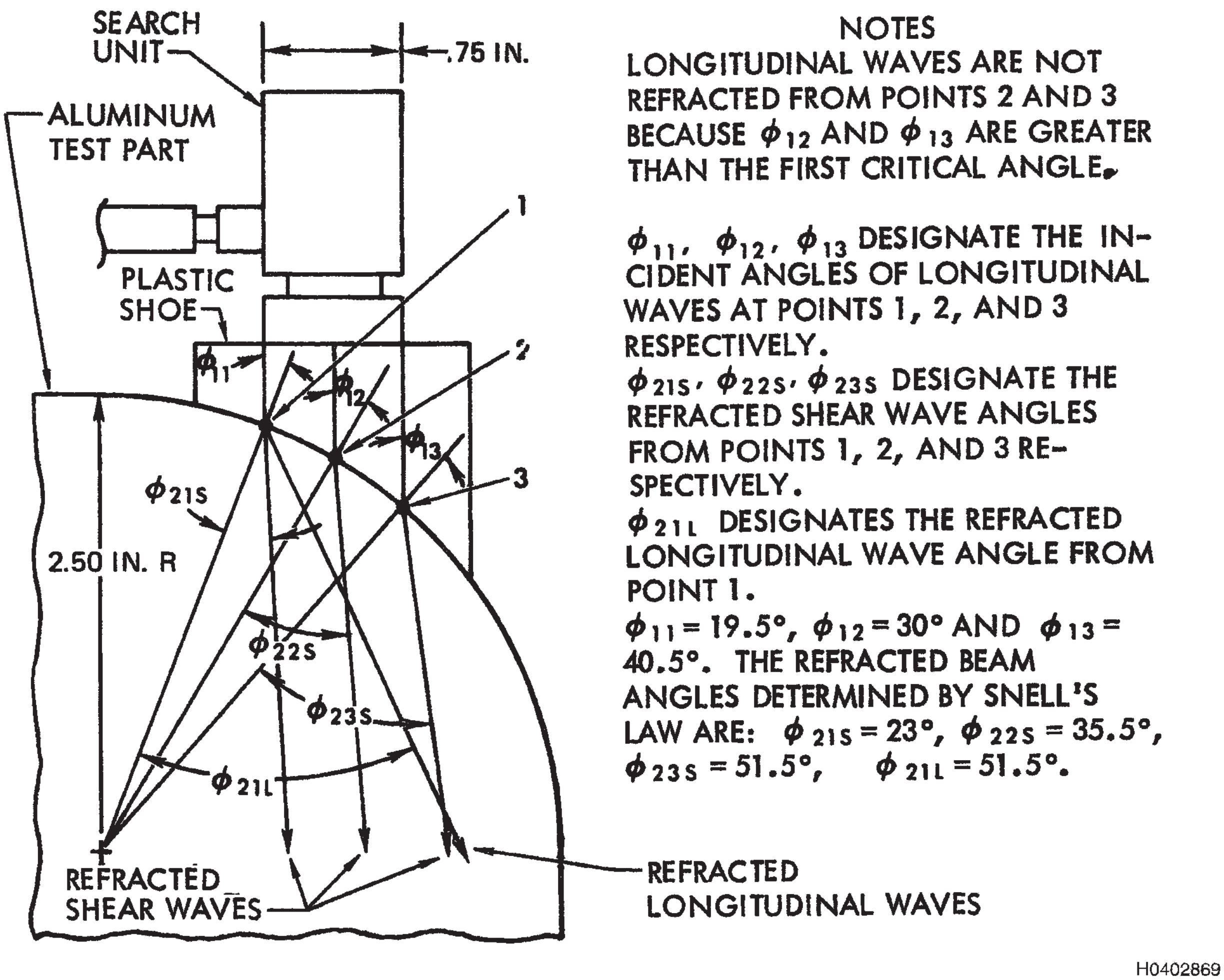


Figure 5-35. Example of Determining the Sound Beam Path in a Test Part With a Curved Surface

5.3.4.2.11 With certain inspection setups, particularly when using shoes to generate straight beams (paragraph 5.3.2.3.1) in parts with curved surfaces, multiple reflections from the shoe-to-test part interface can interfere with the inspection. To avoid this, the shoe SHALL be made thick enough to avoid interference with the intended inspection application. Consider the inspection setup shown in Figure 5-36. It is important only that the inspector be able to recognize and identify indications on the waveform display. Reflections caused by the shoe are easily recognized simply by raising the shoe off the surface of the material. If the indications remain on the screen, the plastic shoe is the cause. Slotting the shoe as shown in Figure 5-33 may reduce or eliminate such interference signals. It is not necessary for the operator to calculate the sound paths to and from various reflectors; however, it is important the operator know how to recognize non-relevant indications from the reflectors and minimize their cause.

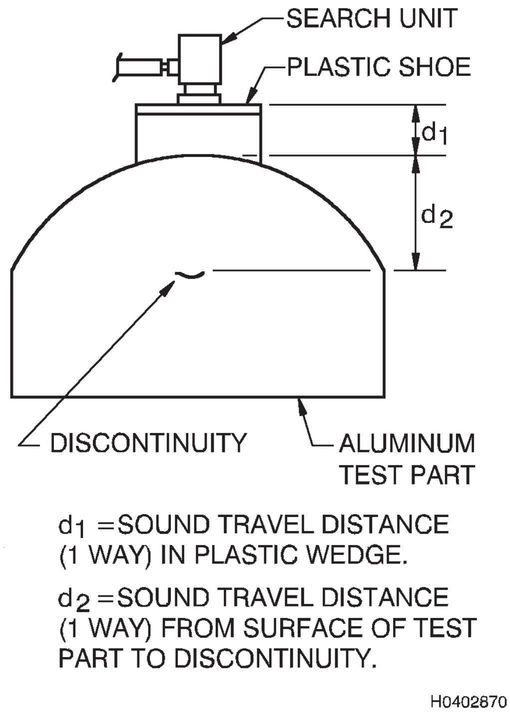


Figure 5-36. Straight Beam Inspection of Test Part With Curved Surface

5.3.5 Couplants. Air is a poor transmitter of sound at the frequencies typically used for ultrasonic inspection. Therefore, to perform ultrasonic contact inspection (paragraph 5.4.2.1.1.1) the use of a couplant material is necessary to eliminate the air between the transducer and test piece interface.

CAUTION

"Ultragel" cannot be left on transducer/delay line interfaces for long periods of time because it will corrode the metallic finish of the transducer, seize the connecting ring and transducer housing causing the transducer to become unstable.

NOTE

Glycerin, silicones, and graphite greases SHALL NOT be used as couplants unless authorized by specific engineering approval.

5.3.5.1 Properties of Couplants. Couplant materials SHALL meet the following requirements:

- Couplant SHALL be able to wet both the face of the transducer and the test part.
- Couplant SHALL NOT be corrosive or toxic.
- Couplant can be applied and removed easily.
- Couplant SHALL be homogeneous and free of bubbles.
- Couplant SHALL be viscous (adhere well) enough to prevent rapid flow off the test part.

5.3.5.2 Types of Couplant. Typical couplant materials include water, oil, grease, commercial gels. For overhead or vertical surfaces, higher viscosity materials may be required. Wetting agents MAY be added to water to lower the surface tension and aid in its adherence to the test piece. Water SHOULD be avoided on carbon steel components to prevent corrosion. Petroleum based couplants SHOULD be avoided on fibrous composite materials to prevent adhesive/matrix degradation.

5.3.6 Inspection Standards. To ensure consistency of inspections from inspector to inspector many ultrasonic inspection techniques require the use of a reference standard for setup and/or calibration. The use of an inspection standard allows the operator to adjust the ultrasonic instrument controls properly, ensuring that the combination of ultrasonic instrument and transducer meets the specified sensitivity requirements. Standards can be locally manufactured to specific engineering instructions, an actual failed in-service component, or any one of numerous standard reference blocks.

5.3.6.1 Standard Reference Blocks. These are blocks, whose dimensions have been sanctioned and/or required by professional organizations or commercial codes (e.g., ASME, IIW, AWS, ASTM). Only the most likely used standard reference blocks are described here.

5.3.6.1.1 Area-Amplitude Blocks. The area-amplitude blocks are intended to establish the correlation between the signal amplitude with the area of a flat bottom hole reflector. These sets of blocks contain flat-bottom holes of differing diameters all at the same distance from the sound entry surface.

5.3.6.1.2 Distance-Amplitude Blocks. The distance-amplitude blocks are intended to establish the correlation between the signal amplitude with the corresponding distance to a flat bottom hole reflector. These sets of blocks contain flat-bottom holes of the same diameter all at varying distances from the sound entry surface.

5.3.6.1.3 American Society of Testing and Materials (ASTM) Standard Reference Block Set. Each Air Force NDI laboratory SHALL possess an aluminum alloy ASTM standard reference block set (or AF NDI Office approved equivalent). The dimensions for all ASTM blocks are specified in ASTM E 127, which also includes recommended practices for fabrication and control of the aluminum alloy reference blocks. ASTM E 428 contains the recommended practice for fabrication and control of the steel standard reference blocks.

5.3.6.1.3.1 The basic ASTM block set includes ten, 2.0-inch diameter blocks of the same material stock. Each block has a 0.75-inch deep flat-bottom hole (FBH) drilled in the center of the bottom surface. One block has a 3/64-inch diameter hole at a 3-inch metal travel distance. Seven blocks have 5/64-inch diameter holes at metal travel distances of 1/8, 1/4, 1/2, 3/4, 1.5, 3.0 and 6.0-inches. The remaining two blocks have 8/64-inch diameter holes at 3.0 and 6.0-inch metal travel distances. Each block is identified by a nine-digit code (AAAA-B-CCCC). The first four digits identify the material alloy, the center digit is the diameter of the hole in 1/64-inch, and the last four digits are the metal travel distance from the top surface to the hole bottom in 1/100 inch. For example, the block marked 7075 8 0300 is 7075 aluminum and has an 8/64-inch diameter hole with a 3.0-inch metal travel distance.

5.3.6.1.3.2 The three blocks with 3.0-inch metal travel and 3/64, 5/64 and 8/64-inch are utilized as an area-amplitude set. The seven blocks with #5 (5/64-inch) flat-bottom holes are utilized as a distance-amplitude set.

5.3.6.1.4 International Institute of Welding (IIW) Blocks. Each Air Force NDI laboratory SHALL possess an aluminum alloy and steel, Type 2 IIW standard reference block (or AF NDI Office approved equivalent). The material and dimensional requirements of the IIW blocks are specified by the International Institute of Welding. The Type 2 IIW Blocks are primarily used for measuring the beam exit point and refracted angle of angle beam transducers and for calibrating angle beam metal path distances. Straight beam distance resolution, distance calibration, and near and far surface resolution can also be accomplished with use of certain known notches and block distances.

5.3.6.1.5 Miniature Angle Beam Block. The miniature angle beam block is a smaller and lighter version of the Type 2 IIW block and can be used for the same purpose. However, near and far surface resolution checks CANNOT be performed with the miniature angle beam block.

5.3.6.2 Locally Manufactured Standards. Where locally manufactured standards are specified in a procedure, specific engineering instructions SHALL be provided that detail the manufacturing requirements. Typical ultrasonic standard manufacturing requirements include flat-bottom holes, side-drilled holes, and EDM notches. Flat-bottom holes are used for area-amplitude type calibrations. Side-drilled holes are used for developing distance-amplitude correction (DAC) curves. EDM or other type notches are used to determine the sensitivity to surface breaking flaws such as cracks. Thickness measurement requirements may require the manufacture of step-wedges or other specific thickness components.

5.3.7 Bonded Structure Reference Standards.

5.3.7.1 Configuration. The reference standard MAY be a duplicate of the test part except for the controlled areas of unbond. As an option, simple test specimens which represent the respective different areas of the test part and contain controlled areas of unbond MAY be used. Reference standards SHOULD:

- Be similar to the test part with respect to material, geometry, and thickness. (This includes closure members, core splices, stepped skins, and internal ribs similar to the test part if bonded areas over or surrounding base details are to be inspected.)
- Contain bond(s) of good quality except for controlled areas of unbond fabricated as explained below.
- Be bonded using the adhesive and cure cycle prescribed for the test part.

5.3.7.2 Defect Types. Defects are separated into five general types to represent the various areas of bonded sandwich and laminate structures. The five general types are:

- Type I: Unbonds or voids in an outer skin-to-adhesive interface.
- Type II: Unbonds or voids at the adhesive-to-core interface.
- Type III: Delaminations or voids between layers of a laminate.
- Type IV: Voids in foam adhesive or unbonds between the adhesive and a closure member at core-closure member joints.
- Type V: Water in the core.

5.3.7.3 Fabrication of Bonded Reference Standards. The reference standards SHALL contain unbonds equal to the sizes of the minimum rejectable unbonds for the test parts. Information on minimum rejectable unbond sizes for test parts SHALL be obtained from the prime depot level engineering activity.

5.3.7.3.1 Producing unbonds by use of grease, vinyls, and other foreign material not covered below is prohibited. One or more of the following techniques SHALL be used in fabricating reference defects. Since bonding materials vary, some of the methods may not work with certain materials.

5.3.7.3.1.1 Standards for Types I, II, III, and IV unbonds MAY be prepared by placing discs of 0.006-inch thick (maximum) Teflon sheets over the adhesive in the areas selected for unbonds. For a Type-II unbond, place the Teflon between the core and adhesive. Assemble the components of the standard and cure the assembly.

5.3.7.3.1.2 Types I, II, and III standards MAY also be produced by cutting flat-bottomed holes of diameter equal to the diameter of the unbonds to be produced. The holes are cut from the backsides of bonded specimens, and the depths are controlled to produce air gaps at the applicable interfaces (Figure 5-37). When using this method, patch plates MAY be bonded to the rear of the reference standard to cover each hole and seal the reference standard.

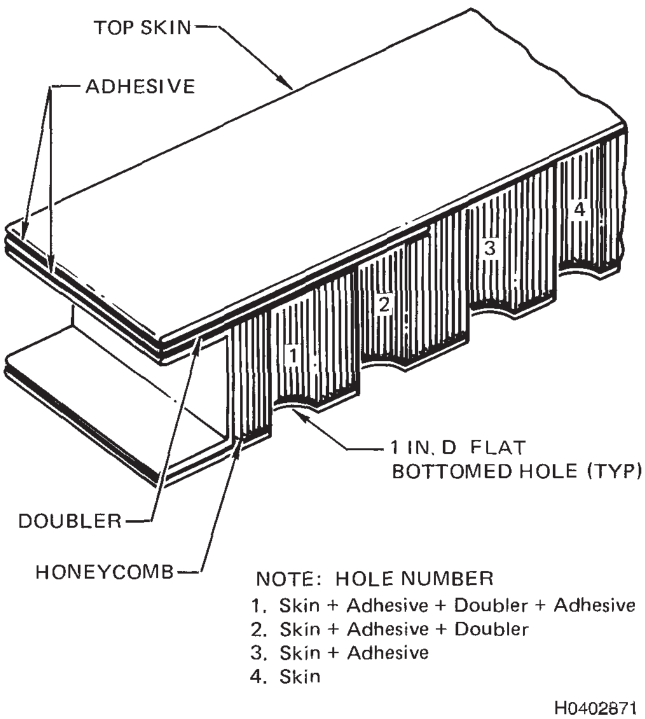


Figure 5-37. Example of Reference Standard for Types I and II Unbonds

5.3.7.3.1.3 Type II standards MAY be produced by locally undercutting (before assembly) the surface of the core to the desired size unbond. The depth of undercut SHALL be sufficient to prevent adhesive flow, causing bonds between the undercut core and the skin.

5.3.7.3.1.4 Type IV standards MAY be produced by removing adhesive in selected areas prior to assembly.

5.3.7.3.1.5 Type V standards MAY be produced by drilling small holes in the back of the standard and injecting varying amounts of water into the cells with a hypodermic needle. The small holes can then be sealed using a small amount of water-resistant glue or adhesive.

5.3.8 Thickness Measurement Equipment. A written procedure SHALL specify equipment, transducer, reference standard, and calibration requirements.

5.3.8.1 Thickness Measurement Instruments. Some ultrasonic instruments are designed specifically for thickness measurements and typically have a digital read-out. Some basic ultrasonic instruments also have built-in thickness measurement options. Detailed instructions for performing thickness measurement with these instruments MAY be obtained by consulting the specific instrument manual.

5.3.8.2 Thickness Measurement Transducers. Transducers for thickness gauging are highly damped for a very short duration pulse for best resolution. With general purpose flaw detectors, best results will usually be obtained by using transducers specifically designed for thickness gauging. Typically, transducers with a narrow dead zone and superior near-surface resolution are required for measurement of thin materials. Therefore, dual-element transducers/search units with delay lines are routinely used. For measurements of thicker materials, a conventional straight beam contact transducer MAY be sufficient. Instruments dedicated to thickness measurements are often supplied with compatible transducers. These often have unique connectors to ensure only dedicated probes are used. Transducers recommended by the instrument manufacture SHALL be used with dedicated thickness measurement instruments. With a dual-element transducer, the ringing of the transducer element is not detected by the instrument; therefore, received signals close to the initial pulse can be clearly resolved. Dual-element transducers are limited in how thin they can measure by virtue of the elements being side-by-side. A plastic delay line coupled to the face of a single-element transducer separates the initial pulse from the front surface signal; this improves near-surface resolution (e.g., shortens the dead zone).

5.3.8.3 Thickness Measurement Reference Standards. Reference standards are required to calibrate the instruments prior to thickness inspection (paragraph 5.7.8). The material and heat treat condition of the reference standards SHOULD be the same as the test part. The sound velocity in the reference standard SHALL be the same, within acceptable tolerances, as in the part being measured or a correction factor SHALL be used. Thickness measurements of curved and radiused parts may require reference standards with the same curvature. In addition, transducers with curved wedges/shoes to match the contour of the part may be required.

SECTION IV ULTRASONIC INSPECTION APPLICATION

5.4 INTRODUCTION.

5.4.1 Guidelines for Inspector Familiarization. Familiarization with the methods and equipment can be obtained by:

- Performing the familiarization tests included in the instrument manuals.
- Performing the calibration procedures.
- Making distance amplitude correction (DAC) curves (paragraph 5.4.8) and establishing transfer (paragraph 5.4.9) on some specimens.
- For surface wave familiarization, (paragraph 5.4.8.1).

5.4.1.1 All familiarization tests and procedures SHOULD be followed in detail by new inspectors. It is recommended the procedures be run through several times. The inspector SHOULD experiment with various combinations of specimens and transducers to become familiar with different ultrasonic inspection procedures and equipment.

5.4.2 Basic Ultrasonic Inspection.

5.4.2.1 Coupling Methods.

5.4.2.1.1 Contact and Immersion Testing. The transducer must be adequately coupled to the test piece to ensure adequate sound transmission. Coupling is accomplished either through direct contact with the test piece or through a fluid interface between the transducer and the test piece. Thus, coupling methods can be separated into two basic categories: contact inspection and immersion inspection.

5.4.2.1.1.1 Contact Inspection. Contact Inspection is the method in which the transducer makes direct contact with the material. The contact method requires the use of a couplant to ensure sufficient ultrasonic energy transmission into the part. The couplant is an approved substance (usually a liquid) applied as a thin film between the transducer face and the test piece.

5.4.2.1.1.2 Immersion Inspection. Immersion inspection is an examination method where the transducer and the material are submerged in a tank of water Figure 5-38). In some instances, a water column is maintained between the transducer and test material. In either case, the water must be free of air bubbles and other foreign material that could interfere with ultrasonic tests. If necessary, corrosion inhibiting agents and wetting agents MAY be added to the water to inhibit corrosion and to reduce the formation of air bubbles on the material and transducer surfaces. Immersion inspections are no longer confined to a tank of water in a laboratory or factory. Bubblers, squirters, and water columns enable the use of immersion techniques with portable ultrasonic scanning equipment in field inspections.

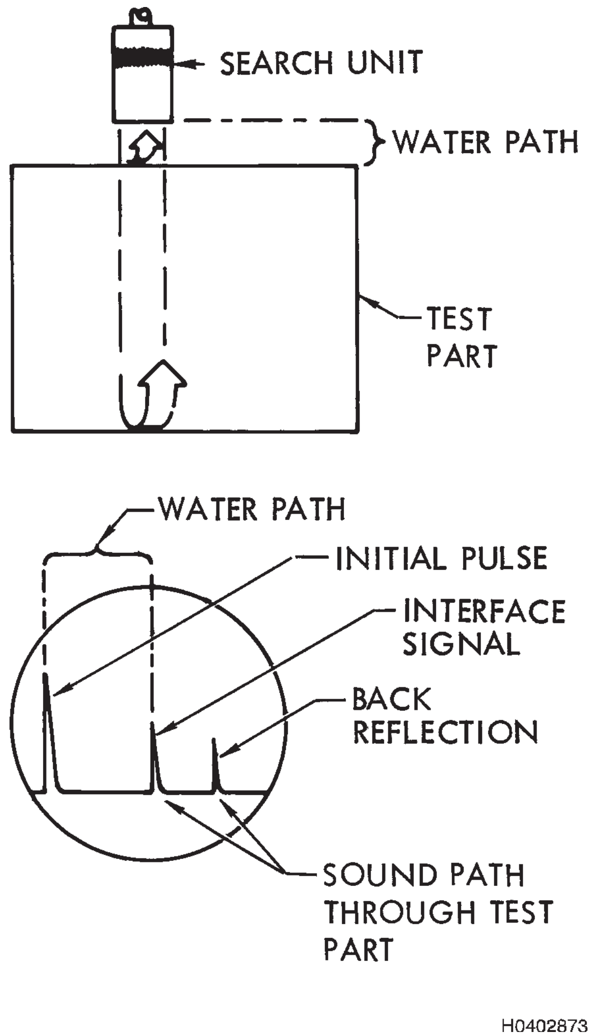


Figure 5-38. Immersion Method

5.4.3 Ultrasonic Reflections. Ultrasonic sound beams have properties similar to light beams. For example, when an ultrasonic beam strikes an interrupting object, sound beam energy is reflected from the surface of the interrupting object. The angle of incidence is equal to the angle of reflection (Figure 5-39).

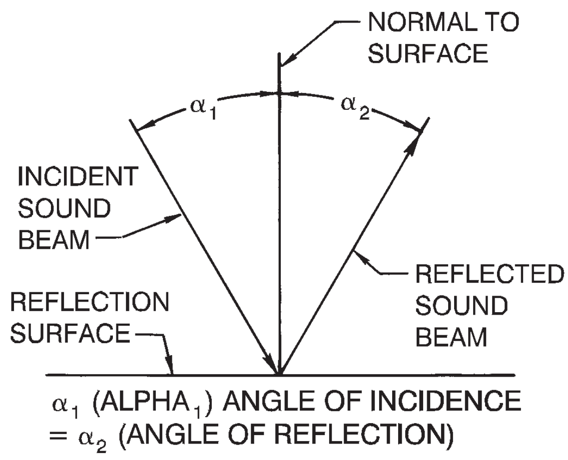


Figure 5-39. Ultrasonic Reflection

5.4.4 Data Presentation Methods. There are three methods of data presentation used for ultrasonic inspection: A-scan, B-scan, and C-scan.

5.4.4.1 A-Scan. An A-scan presentation is a plot of time versus amplitude and is displayed on an ultrasonic instrument in the form of a horizontal baseline that indicates time or distance. A-scan signals deflect vertically from the baseline to indicate the amplitude of electrical pulses (echoes) received from the transducer. On a calibrated ultrasonic instrument, flaw depth can be determined from the horizontal position of the echo on the baseline. The upper half of Figure 5-40 represents an A-scan display corresponding to the contact inspection shown in the lower half of the figure. A-scan presentations are the most utilized ultrasonic data presentation method and are also referred to as distance-amplitude presentations.

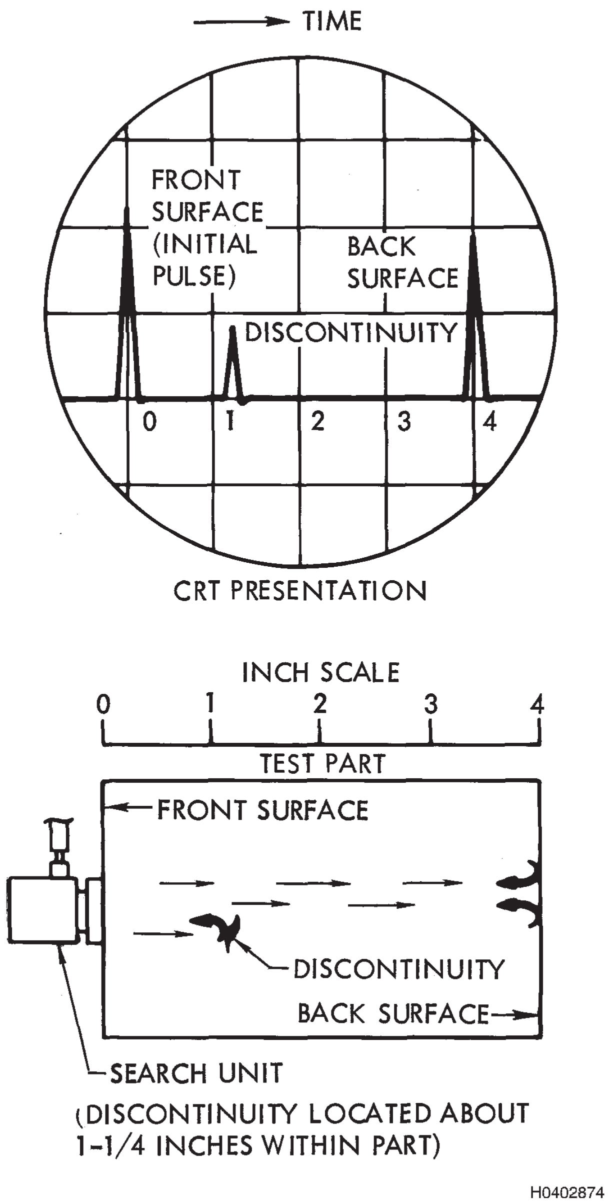


Figure 5-40. Typical A-Scan Display for Contact Inspection

5.4.4.2 B-Scan. A B-scan presentation provides a cross-sectional view of the test piece. This requires a device encoder that plots the time of arrival of the pulse, as a function of the physical location of the transducer. B-scans are typically generated by scanning the transducer at a uniform rate, in a straight line across the surface of the test piece. B-scans may be displayed in real-time on the ultrasonic instrument, an external monitor, or an x-y plotter.

5.4.4.3 C-Scan. A C-scan presentation provides a plan view of the material and discontinuities therein. This is accomplished by collecting an electronically gated output of an A-scan presentation. The C-scan is generated as the part is scanned in a raster pattern with a manual or automated two-axis scanner. Discontinuities are indicated at positions corresponding to the actual x-y locations of the discontinuities in the part (Figure 5-41). Device encoders to track and relay transducer position to the recorder or display are required. Typically, video displays are produced after the analog signal is converted to digital data. The display can be adjusted so different colors or shades of gray represent different depths or thickness. Signal amplitudes can also be displayed in various colors schemes. Numerous image processing tools may be available to the operator depending on system capabilities.

Figure 5-41. A-Scan, B-Scan and C-Scan Presentation Examples

5.4.5 Relationship of a Scan Waveform Display to Distance. In a test part containing a discontinuity, ultrasonic energy is reflected as echoes from the discontinuity and the back surface of the test part. Referring back to Data Presentation Method, there are three methods of data presentation used for ultrasonic inspection: A-scan, B-scan, and C-scan. Notice the positions of the displayed signals on the display screen in relation to the actual positions of the test-part front surface, discontinuity, and back surface. The distance along the display screen baseline is proportional to the distance to the discontinuity and back surface in the test part. The signals on the display screen were adjusted to position the initial pulse on the grid marked “0” and the back surface signal on the grid marked “4.” The discontinuity then appeared just to the right of the grid marked “1.” The adjustments of the signals on the display screen were accomplished by varying two controls on the instrument, the Sweep Delay and the Sweep Length or Range. The adjustment made each space between the vertical grid lines on the display screen equivalent to 1 inch in the test part.

5.4.6 Common Inspection Techniques.

5.4.6.1 Straight Beam (Longitudinal) Pulse-Echo Technique.

5.4.6.1.1 General. This technique uses longitudinal waves (paragraph 5.2.3.1).

5.4.6.1.2 Limitations.

5.4.6.1.2.1 Dead Zone. The dead zone (paragraph 5.2.6.1) interferes with contact inspection (paragraph 5.4.2.1.1.1) of near-surface regions of parts. When required, the coverage of a straight beam inspection in near-surface regions can be extended by several different techniques, such as the following:

- Inspect the part from opposite sides. The dead zone, which is not inspected from the first side, is covered when inspecting from the second side (Figure 5-42).
- Use a dual-element transducer (paragraph 5.3.2.6).
- Use a delay line contact transducer (paragraph 5.3.2.8).
- Use an immersion inspection method.

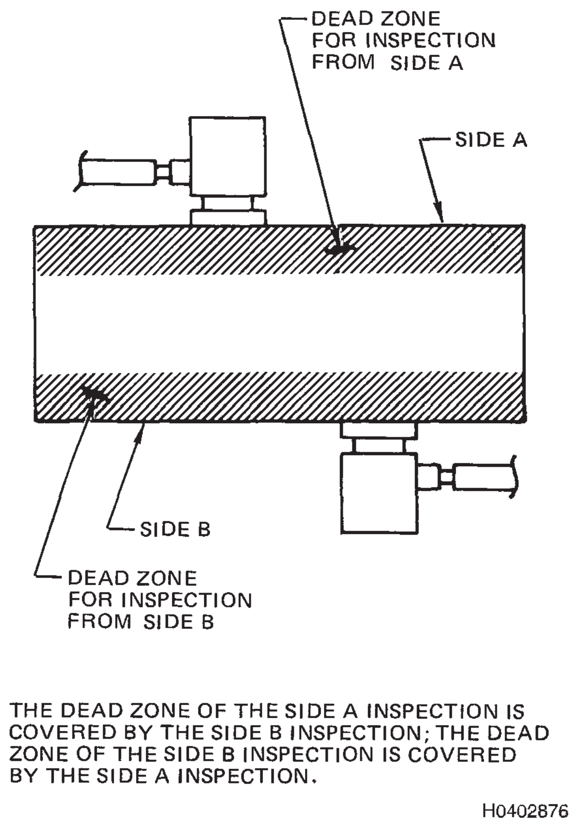


Figure 5-42. Inspection of Test Part Opposite Sides to Provide Coverage of Dead Zone Areas

5.4.6.1.2.2 High Attenuation. In some cases, when inspecting thick sections, the sound energy in the part drops below usable levels. If this happens, inspecting from opposite sides can help, since only half the section thickness needs to be covered in a single inspection. If inspecting from two sides, the zones must overlap by a minimum of 1/2-inch. The through-transmission technique may also help alleviate high attenuation limitations.

5.4.6.2 Straight Beam Multi-Transducer Technique.

5.4.6.2.1 Through-Transmission Technique. Through-transmission also uses the straight beam (paragraph 5.3.2.3.1) method, but this method requires two transducers, one to transmit the signal and one to receive the signal. In through-transmission inspection, a transmitting transducer is placed on one surface and the receiving transducer is placed on the opposite surface of the test piece. In this technique, discontinuities (voids) block the passage of sound resulting in a reduction of the received signal (Figure 5-43). Since the echoes from the discontinuities are not received, the depth of information cannot be determined.

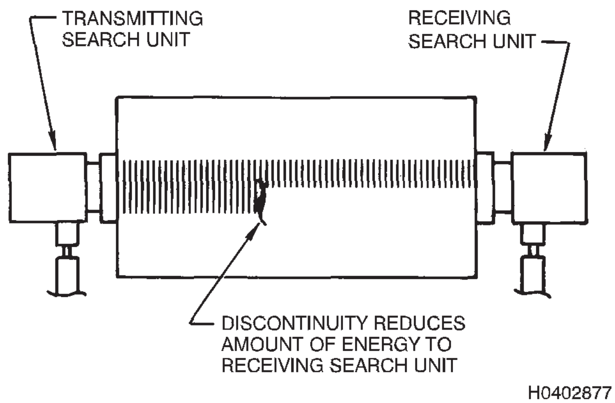


Figure 5-43. Through-Transmission Inspection

5.4.6.2.1.1 Beam Alignment. A major problem encountered with through-transmission testing is maintaining alignment of the transducers. Misalignment can reduce the amplitude of the received signal. Anything causing the received energy to suddenly drop can be misinterpreted as a defect. The through-transmission technique is useful when insufficient energy is obtained with the pulse-echo method and can be applied to inspect thick materials (distances up to 80-feet have been inspected). The through-transmission technique can also be used to advantage on thin test parts when the dead zone prevents an inspection with the pulse-echo method.

5.4.6.2.2 Application of Through-Transmission. The straight beam (paragraph 5.3.2.3.1) technique is used to detect discontinuities with at least one surface oriented parallel to the test surface. Typical discontinuity examples are laminations, corrosion, high-and low-density inclusions, porosity, forging bursts, and cracks. Applications of the straight beam technique depend upon the test part geometry.

5.4.6.3 Angle Beam (Shear Wave) Technique.

5.4.6.3.1 General. This method generally uses shear waves (paragraph 5.2.3.2) refracted in the test part at angles of 30° to 70°.

5.4.6.3.2 Angle Beam Applications. The angle beam technique is used extensively in field nondestructive inspections and can provide for inspection of areas with complex geometries or limited access. This is because angle beams can travel through a material by bouncing from surface to surface. Useful inspection information can be obtained at great distances from the transducer. Angle beam inspections are particularly applicable to inspections around fastener holes, inspection of cylindrical components, examination of skins for cracks, and inspection of welds; Figure 5-44 shows typical angle beam inspections.

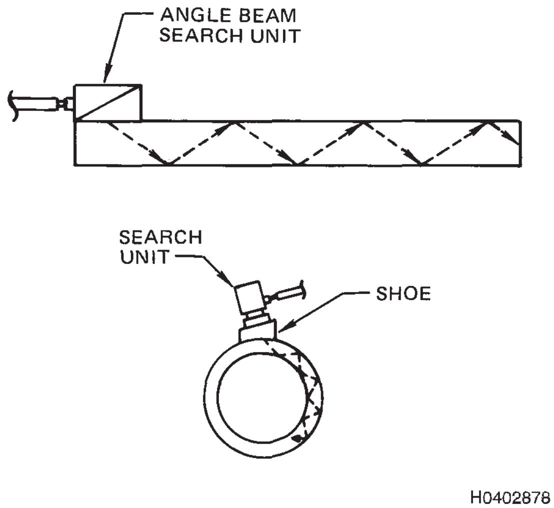


Figure 5-44. Angle Beam Inspection

5.4.6.3.3 Multiple Search Units (Angle Beam). Most angle beam methods use a single transducer with one transducer element for transmitting and receiving ultrasonic energy. Special applications MAY utilize dual angle-beam transducers (Figure 5-23) or two or more angle beam units, one for transmitting, the rest for receiving, but due to beam alignment issues, this technique generally requires special fixtures to ensure correct transducer spacing and alignment.

5.4.6.4 Surface Wave (Rayleigh) Technique.

NOTE

When surface waves are used to inspect painted surfaces, the technician SHOULD be aware during setup and interpretation, the possibility of surface reflection from scratches and breaks in the painted surface. Rough surfaces or liquid on the surface can also attenuate surface waves. When sliding a transducer toward and then away from the suspect area, a ridge of couplant is often created that can reflect part of the surface wave energy and be mistaken for a crack. The area in front of the transducer SHALL be kept free of all, but the minimum amount of couplant needed for the inspection.

5.4.6.4.1 General. This technique uses surface (Rayleigh) waves (paragraph 5.2.3.3) refracted in the test part at an angle of 90°. These waves propagate such that they must be bounded by air along the surface of the test specimen so this technique will work only during contact inspections (paragraph 5.4.2.1.1.1).

5.4.6.4.2 Surface Wave Applications. Surface wave inspections can be utilized in many field NDI applications involving surface cracks or slightly subsurface discontinuities. On smooth surfaces, sound energy can travel long distances with little energy loss. Surface waves travel around curved surfaces. They reflect at sharp edges (radius less than one wavelength). Complete reflection does not occur even at sharp edges.

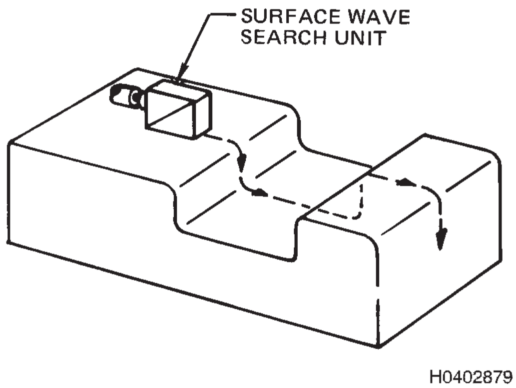


Figure 5-45. Surface Wave Inspection

5.4.6.4.3 Surface Wave Familiarization.

a. Use a miniature angle-beam block. Attach a 2.25 MHz surface wave transducer to the ultrasonic instrument.

b. Position the transducer at P-1 as shown in Figure 5-46. Adjust the sweep and gain to obtain a signal from corner C.

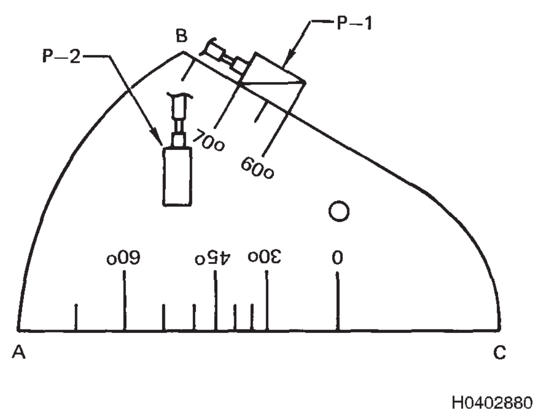


Figure 5-46. Surface Wave Familiarization

c. Moisten a finger with couplant and move it across the surface from the transducer toward corner C.

NOTE

The corner signal is damped until the finger moves beyond the corner.

d. Move the transducer away from corner C toward corner B as shown in Figure 5-46.

NOTE

The corner C signal moves to the right along the time base.

e. Position the transducer at P-2 as shown in Figure 5-46. Orient the transducer perpendicular to edge AC. Adjust the sweep and gain to obtain a signal from edge AC.

f. Rotate the transducer and note the signal from the edge decreases as the transducer is rotated away from the normal to the edge. This illustrates surface waves SHOULD always be directed perpendicular to the expected plane of cracks (Figure 5-47).

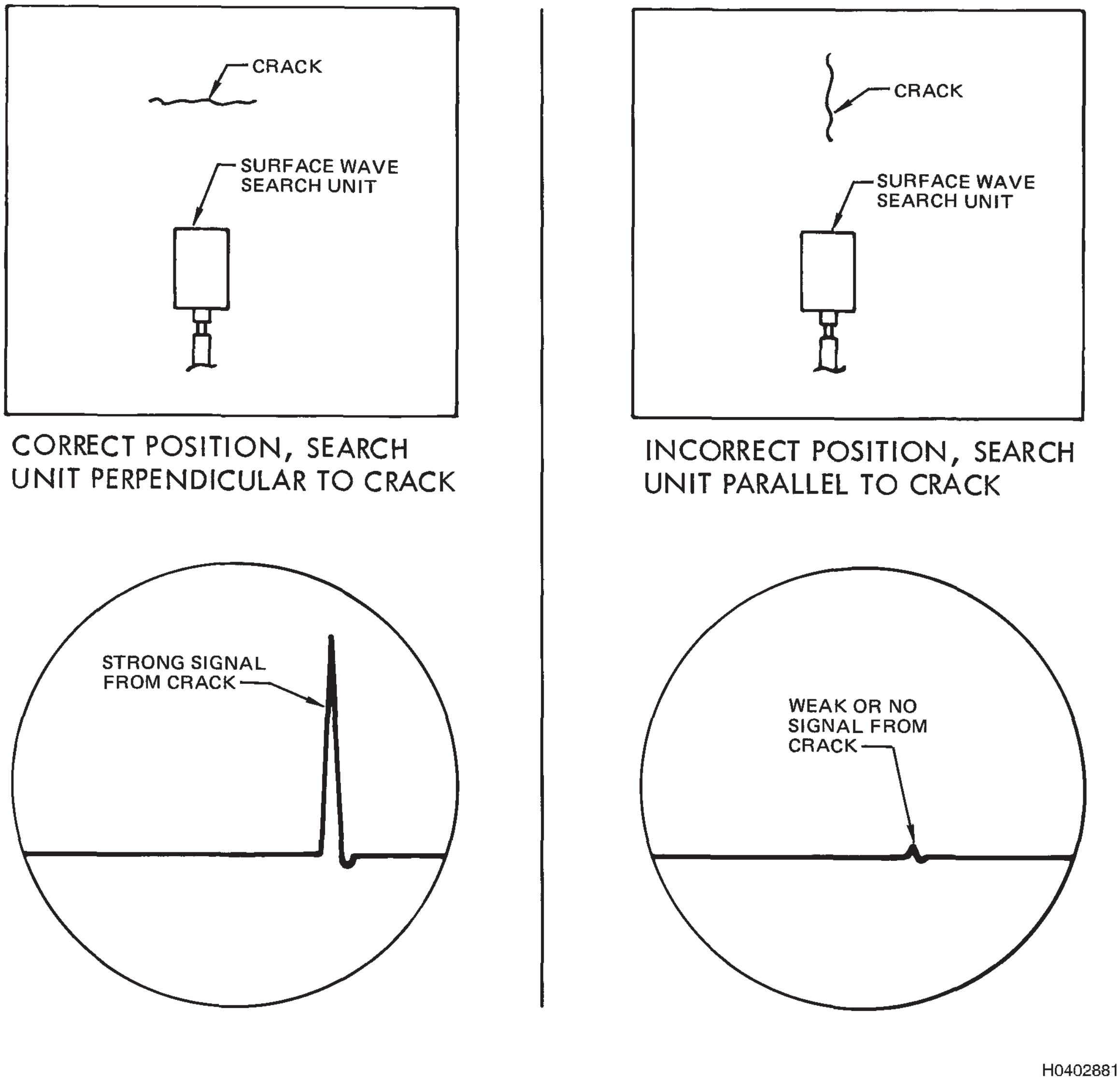


Figure 5-47. Correct and Incorrect Transducer Orientation for Finding Cracks With Surface Waves

5.4.6.5 Lamb (Plate) Wave Technique. If the thickness of a test part is less than one wavelength of the sound introduced at the appropriate incident angle, lamb waves (paragraph 5.2.3.4) travel between the two parallel surfaces of the part. This is a special technique not widely used.

5.4.7 Ultrasonic Technique Development. As with the other NDI disciplines, most ultrasonic techniques used in the field are established at the depot. In certain situations, it MAY be necessary to develop a technique in the field. If such a need arises, the following information will aid in developing the required techniques. The information may also lead to a better understanding of established techniques.

5.4.7.1 Information Required. When establishing an ultrasonic inspection technique, it is first necessary to obtain as much information as possible about the test part. Information required is as follows:

- Type of material to be inspected, and heat treatment
- Surface condition
- Accessibility
- Shape/geometry of test part
- Type of discontinuity to look for
- Expected location and orientation of discontinuity
- Expected orientation of discontinuity with respect to sound path
- Size defect that must be reliably detected (acceptance/rejection criteria)
- Inspection technique required
- Inspection zones, if applicable

5.4.7.1.1 Information on many of the above items can be obtained by visual examination of the test part and study of applicable manuals and drawings. Examination of failed parts is helpful for obtaining information on the location of and type of discontinuity causing failure.

5.4.7.2 Defining the Technique. The information required by (paragraph 5.4.7.1), along with the information in this chapter, is used to establish the technique variables. In addition, if welds are to be inspected (TO 00-25-224). Items that need to be defined are listed below and described in more detail in the subsequent paragraphs.

- Inspection surfaces.
- Mode(s) of inspection: longitudinal, shear and/or surface wave, contact, or immersion.
- Scanning plan.
- Reference standard(s).
- Transfer method.
- Frequency.
- Transducer.
- Requirements for special wedges or shoes.
- Surface preparation required and method to be used.
- Type of couplant used.

5.4.7.2.1 Inspection Surfaces, Scan Plan, and Mode(s). The expected location and orientation of discontinuities, along with accessibility of the inspection area, are used to help define which surfaces will be used for sound entry, the mode(s) of sound energy used, and the scanning procedure. The sound SHOULD be directed normal to the expected plane of the largest surface of the discontinuity. Therefore, straight beam (paragraph 5.3.2.3.1) inspection would be used to locate laminar discontinuities, and angle beam inspection would be used to locate internal discontinuities not parallel to the inspection surface. For many angle beam inspections, the sound is directed so it bounces back from a corner formed by a crack and the far surface or a fastener hole. When discontinuities are expected on the inspection surface, a surface wave inspection may be a better choice.

5.4.7.2.2 Reference Standard. The reference standard SHOULD be fabricated from material with the same acoustic properties as the test part. When possible, the reference standard SHOULD be of the same alloy, heat treat condition, same hot/cold work condition, and the same surface condition as the test part. When the material condition of the standard cannot exactly match the part, a transfer technique (paragraph 5.4.9) may be needed to compensate for the differences. The geometry of the reference standard SHOULD match the geometry of the test part so the sound path will be the same. The simulated discontinuities SHOULD be in accordance with the applicable specification for the test part. Refer to SAE-AMS-STD-2154 or ASTM E2375 for general information.

5.4.7.2.3 Frequency Selection. The frequency is selected based upon the acceptance criteria, and the acoustic properties of the test part. A good rule to remember is, “Use the highest frequency that will provide the necessary depth of penetration.” When geometry permits, the test part SHALL be checked at the intended frequency to verify a strong back reflection is obtained. The frequency SHOULD also be appropriate for detecting the minimum size discontinuity anywhere in the test part. Frequencies in the range of 2.25 MHz, 5 MHz and 10 MHz are popular for inspections. When using both the angle beam method (either refracted shear or longitudinal wave) (paragraph 5.3.2.3.2) and the straight beam method (longitudinal wave) (paragraph 5.3.2.3.1), the frequency used for the angle beam shear wave inspection SHOULD be about one-half the frequency used for the straight beam inspection. This provides approximately the same wavelength for both the longitudinal and shear waves (paragraph 5.2.3.2). Refracted longitudinal wave inspection SHOULD be at the same frequency used for straight longitudinal wave (paragraph 5.2.3.1) inspection.

5.4.7.2.4 Transducer Selection. The transducer is selected based on the requirements for mode, frequency, beam direction, and beam size. The part geometry and the limitations on accessibility to the inspection surface determine if special wedges or shoes are required. Refer to (paragraph 5.3.4) for information on wedges and shoes.

5.4.7.2.5 Surface Preparation. The sound entry surface is visually examined to determine if any special preparation is required to provide a suitable condition for ultrasonic inspection. The surface finish SHOULD be 250-microinches or smoother. Painted surfaces can normally be inspected without removing the paint, if the paint is uniform and is tightly adhered to the part surface. Loose or uneven, patchy paint SHALL be stripped prior to ultrasonic inspection.

5.4.7.2.6 Couplant Selection. The couplant is selected based upon the surface condition, the surface orientation, and the information in (paragraph 5.3.5).

5.4.8 Distance Amplitude Correction (DAC) Curve.

5.4.8.1 General. Distance Amplitude Correction (DAC) is not a process control, but is used when it is necessary to compensate for sound attenuation with increasing metal travel distance. Many instruments have built-in DAC features, in these cases; follow the instructions in the operator’s manual for establishing a DAC curve.

a. A typical DAC curve is shown in Figure 5-48.

b. A DAC curve is usually not necessary for surface wave inspections, because the transducer can generally be moved back and forth from a discontinuity to maximize the signal. If a DAC curve is needed for a surface wave inspection, it can be easily established. The transducer is placed at a few points at different distances from the reference standard reflector. At each point, the peak amplitude is measured and marked on the display. A smooth curve is then drawn through the points as in the straight beam (paragraph 5.3.2.3.1) and angle beam (paragraph 5.3.2.3.2) procedures.

5.4.9 Attenuation Correction (Transfer).

5.4.9.1 Description. Transfer (attenuation correction) refers to methods used to compensate for differences in ultrasonic transmission characteristics between the test part and the reference standard. For example, the surface condition of the reference standard, test part, and the internal structures (e.g., grain size, heat treat condition, etc.) could differ. Such differences may cause the signal from a discontinuity in the test part to differ from the signal from the same size discontinuity in the reference standard. In order to obtain consistent results from ultrasonic inspections, it is necessary to use transfer to correct for these differences.

5.4.9.2 General Procedure.

a. Transfer SHALL be accomplished by making note of the dB or gain difference in the responses received from reflectors in the reference standard and the part or piece of material to be inspected.

b. Use the echo signals from the same type of reflector in both the reference standard and the test part to establish transfer. For example, use back surfaces, flat-bottom holes, side-drilled holes or “V-notches” (for angle beam inspections). If possible, a minimum of four reflections from different locations in the part or piece of material to be tested SHALL be noted, and the lowest response SHALL be used for comparison with the response from the reference standard. In practically all cases, any alteration of the test part is prohibited. Therefore, transfer SHALL be accomplished using reflectors already included in the test part. Typical reflectors are the back surface or a fastener hole.

5.4.9.3 Examples of Transfer.

5.4.9.3.1 Straight Beam Inspection of a Two Inch Plate.

NOTE

Newer UT machines with Time Controlled Gain (TCG) eliminate the need for manual transfer.

a. Suppose a specification requires any material with a discontinuity signal greater than the signal from a 5/64-inch diameter FBH is unacceptable. The inspection is set up by establishing a DAC curve in accordance with (paragraph 5.4.8.1). Use ASTM blocks with 5/64-inch diameter FBH's and metal travel distances of 1/8, 1/4, 1/2, 3/4, 1-1/2, and 3-inches. Ass in Figure 5-48 is obtained.

NOTE

Since the dead zone extends beyond 1/8-inch, the 1/8-inch point is not shown. Also notice, the near field appears to end around 3/4-inch.

b. After constructing the DAC curve, the amount of transfer is established through use of back surface reflections. The transducer is placed on the 1 1/2-inch metal travel ASTM standard as shown in Figure 5-48. This gives 2 1/4-inch metal travel to the back surface. The gain control is set to bring the back surface signal to the DAC curve as shown in Figure 5-49. This gain setting is maintained, and the transducer is placed on the test part. Assume the first signal shown is obtained. This is 50-percent lower or 6 dB lower than the DAC curve at the 2-inch metal travel distance. This is the amount of transfer; the amount by which the gain must be increased after calibration.

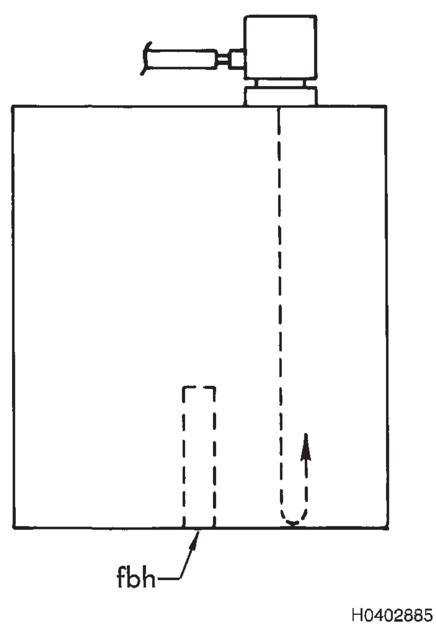


Figure 5-48. Transducer on ASTM Block for Determining Transfer Amount

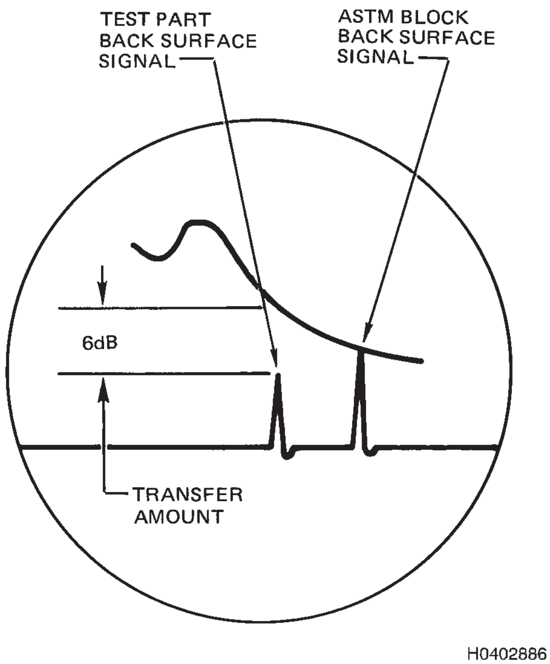


Figure 5-49. ASTM Block and Test Part Back Surface Signals

c. The transducer is now placed on the ASTM block with 1 1/2-inch metal travel distance to the FBH. The signal from the FBH is maximized, and the gain is adjusted to bring the signal to the DAC curve level. Transfer is now applied by increasing the gain setting to double the amplitude. On an instrument with dB gain controls, this is easily accomplished by adding 6 dB to the gain or subtracting 6 dB of attenuation. On an instrument without dB controls, the gain must be increased to double the amplitude of a signal on the display. A correct way of doing this is as follows:

(1) Place the transducer on the 3-inch travel distance block and adjust the position for maximum signal from the FBH. Note the amplitude of the signal. (It SHOULD be close to 30-percent of full screen height.)

(2) Increase the gain until the amplitude of the signal is doubled (e.g., 30-percent to 60-percent). The gain is now set for evaluation of discontinuities in the test part. Any discontinuity signal that exceeds the DAC curve is cause for rejection.

NOTE

Doubling the gain by doubling the signal (e.g., 50-percent saturation to 100-percent saturation) from the flat bottom hole in the 1 1/2-inch metal travel distance ASTM block would be improper; the 100-percent of saturation signal is in a possible nonlinear area of the display. Signals at levels above 90-percent of saturation SHALL NOT be used for applying transfer.

d. The gain setting obtained after applying transfer is used for evaluation of discontinuities in the test part. It is advisable to perform the initial inspection using an even higher gain setting. This provides for more reliable detection of discontinuities. When discontinuities are found, the gain is reduced to the level established by the transfer technique. At this gain setting, any discontinuity signal that exceeds the DAC curve is cause for rejection.

NOTE

In the above example, the metal travel distances to the back surface of the reference standard and the test part were not equal. By using the DAC curve in establishing the transfer, this difference was corrected.

5.4.9.3.2 Transfer of Angle Beam Inspection for a Skin Crack. Use a reference standard configuration as shown in Figure 5-50. The reference standard SHOULD be same thickness and material as skin to be examined. Specify the size of the saw cut; the inspection is set up using the saw cut to establish the sensitivity. Any discontinuity having a signal exceeding 25-percent of the saw cut signal is cause for rejection. Transfer is established as follows:

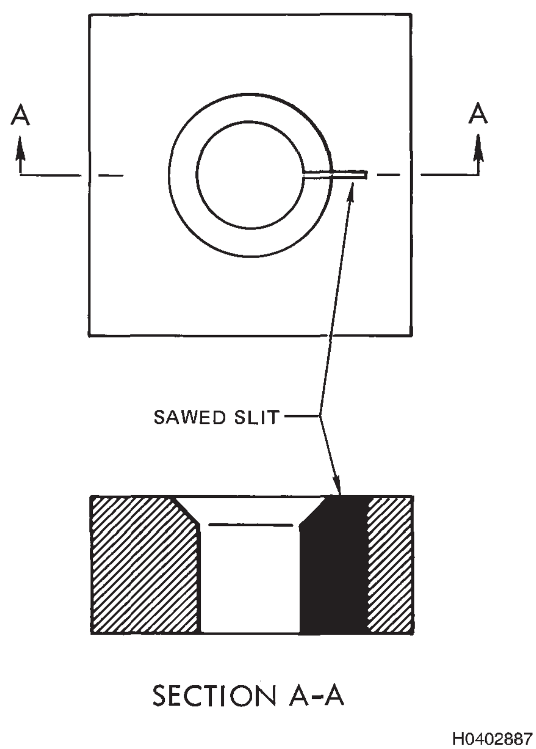


Figure 5-50. Reference Standard for Inspection for Cracks in Skin

a. Place the transducer on the reference standard, as shown in Figure 5-51, and position it to obtain a maximum signal from the top corner of the wall of the fastener hole. Adjust the gain to bring the signal to 50-percent of saturation.

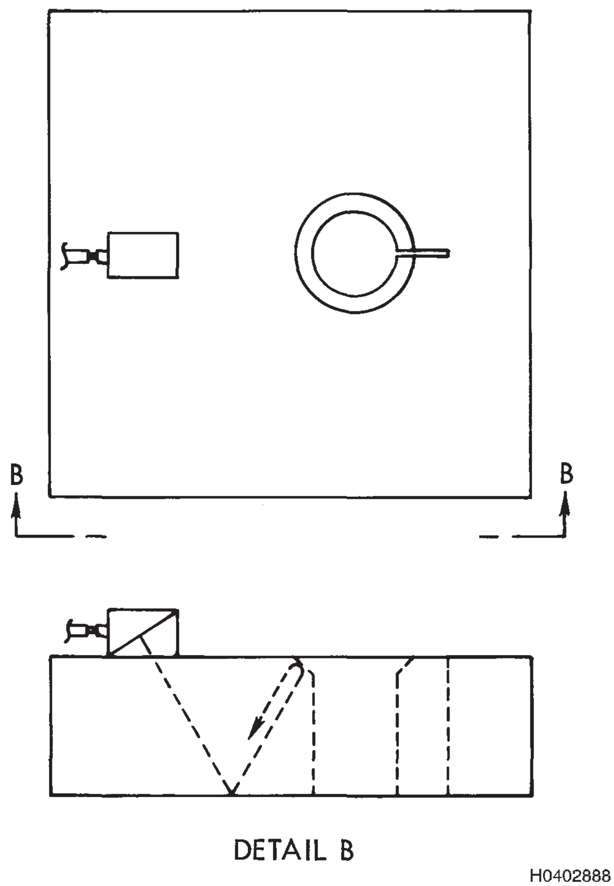


Figure 5-51. Positioning Transducer for Establishing Transfer

b. Place the transducer on the skin, and maximize the signal from the same size fastener hole as in the standard by adjusting the position of the transducer. The gain setting used for the fastener hole in the standard SHALL NOT be changed.

c. Suppose the signal obtained from the fastener hole in the skin is 80-percent of saturation. This is an increase of 60-percent (4 dB) of the signal from the reference standard fastener hole (30 = 60-percent of 50). This is the amount of transfer, the amount by which the rejection (alarm) level has to be raised.

d. Place the transducer back on the reference standard to obtain the signal from the saw cut. Increase the gain until the signal is at some convenient level, for example, 80-percent of saturation. At this gain 20-percent of full scale would be the rejection level, since any signal exceeding 25-percent of the saw cut signal is cause for rejection; however, this rejection level must be increased to 32-percent of full scale by the amount of transfer (60-percent or 4 dB). Therefore, any discontinuity that exceeds 32-percent of saturation is cause for rejection. As in the previous example, the initial scanning is performed at a higher gain setting.

5.4.9.3.3 Straight Beam Technique of Transfer Applied to Angle Beam Inspection. The straight beam inspection (paragraph 5.3.2.3.1) technique of transfer (paragraph 5.4.9.3.1) may also be applied to angle beam inspections. A straight beam transducer is used to determine the amount of transfer. This amount of transfer is then applied to the angle beam inspection. When using this technique, the following conditions SHALL be met.

5.4.9.3.3.1 The frequency of the straight beam transducer SHALL be approximately double the frequency of the angle beam transducer. For a 2.25 MHz angle beam transducer, use a 5 MHz straight beam transducer. For a 5 MHz angle beam transducer, use a 10 MHz straight beam transducer.

5.4.9.3.3.2 The back surface of the standard and the test part must be located in the far field of the straight beam transducer.

5.4.9.3.3.3 The back surfaces of the reference standard and the test part must be parallel with the front surfaces.

5.4.9.4 Transfer Limits. When using the transfer technique, if the signal from the test part is less than 25-percent (-12 dB) or more than 60-percent (+4 dB) of the signal from the reference standard (Figure 5-52), the reference standard may be of the wrong material, heat treat condition and/or surface condition. If the signal from the test part is not within the above limits, another reference standard SHOULD be tried, or the prime depot SHOULD be contacted.

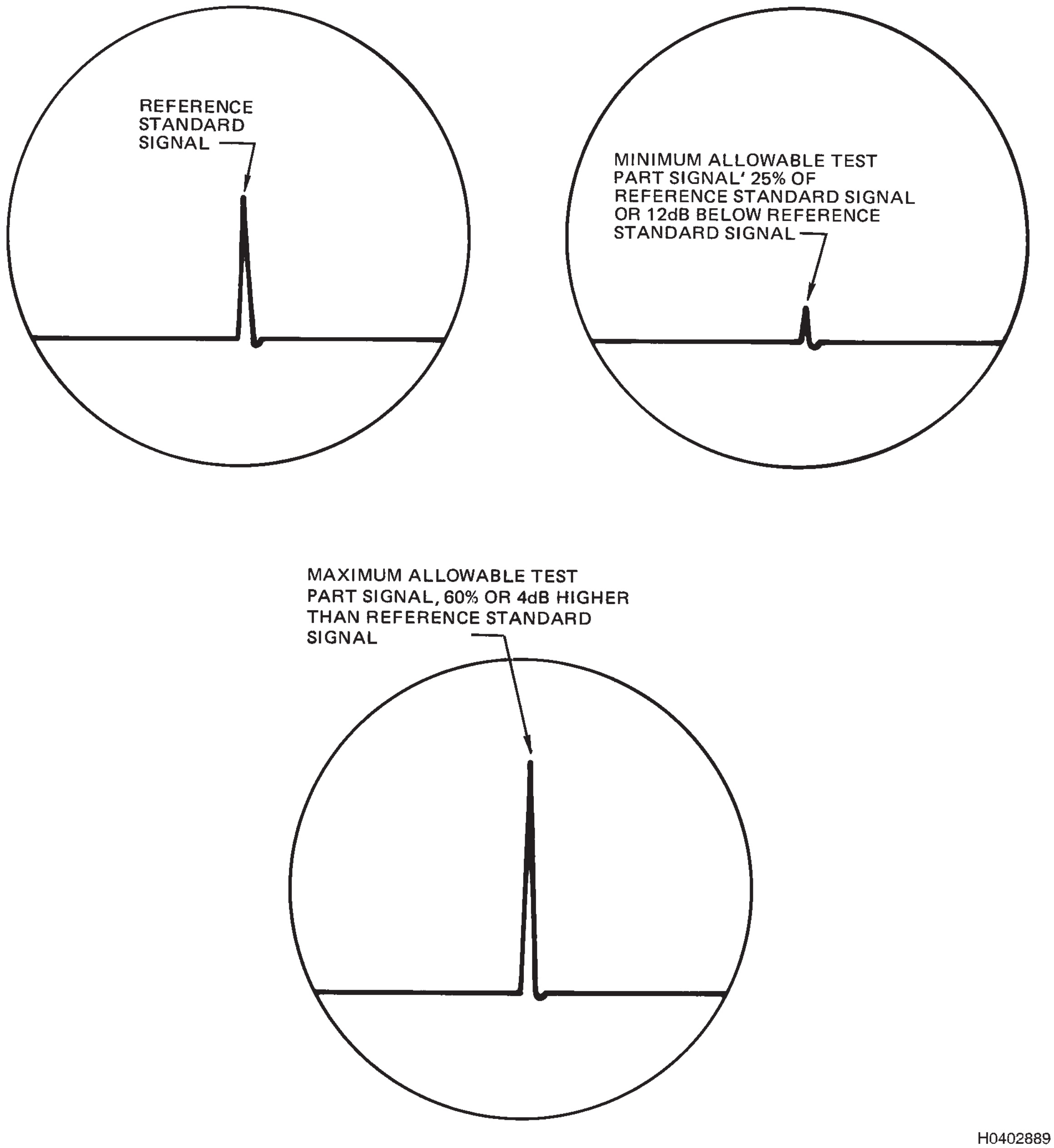


Figure 5-52. Transfer Limits

5.4.10 Inspection of Bonded Structures.

5.4.10.1 Definition. A bonded structure is one consisting of two or more components adhesively bonded together. The structure can be all metallic or nonmetallic, or it can consist of both types of material. A bonded structure can contain honeycomb or other type of light-weight core. Sheets of metal or nonmetal can be bonded together to provide the appropriate thickness. Carbon/epoxy composites are bonded structures although the individual layers are only a few thousands of an inch thick, and essentially lose their individual identity in the curing process; however, separations (delaminations) do occur between layers as a result of external impacts with foreign objects.

5.4.10.2 Variables Applicable to Bonded Structures. There are many configurations and types of bonded structures, thus, there are many variables to consider when performing NDI.

- Probe-side skin material and thickness.
- Adhesive type and thickness.
- Underlying structure - core material, thickness of core, cell size, and thickness of cell wall, far-side skin material and thickness, quantity, thickness and material of doublers, attachments of closure members, foam adhesive, steps in skins, internal ribs, and makeup of nonmetallic composite laminates (material, number of layers and layer thickness).
- Accessibility - one skin or both skins.

5.4.10.2.1 All of these variations complicate the application of ultrasonic inspection methods. A method, which works well on one part or in one area of the part, MAY NOT be applicable for different parts or different areas of the same part.

5.4.10.3 Special Requirements. Because of the many inspection configurations, each application must be examined in detail. The advantages and limitations of each inspection method must be considered, and reference standards (representative of the structure to be inspected) SHALL be ultrasonically inspected to verify proposed techniques. Scanning speeds must be identical on both the standard and the test part. Scan line indexing must be no larger than one-half the width of the smallest rejectable discontinuity.

5.4.10.3.1 The internal configuration of the bonded test part must be understood by the operator. Drawings SHOULD be reviewed and, when necessary, radiographs taken to provide a better understanding of the area under investigation. Knowledge of details such as the location and boundaries of doublers, ribs, etc. is required for valid interpretation of ultrasonic inspection results. The boundaries of internal details SHOULD be marked on the test part using an approved marking method.

NOTE

Grease pencils, chalk, or other marking device may harm the material under evaluation (e.g., lead pencil could lead to burn through). The weapons system technical manual SHALL be consulted for guidance on marking methods.

5.4.10.3.2 This section does not include all the information required to establish techniques. Detailed techniques for specific structures SHOULD be obtained from the applicable NDI manual, or from written authority provided by the prime depot level engineering activity. In addition, further information on the operation of specific instruments SHOULD be obtained from the applicable equipment manuals.

5.4.11 Thickness Measurement.

NOTE

State-of-the-art instruments provide highly accurate thickness measurements from 0.005-inch up to several feet. These instruments not only measure thicknesses in inches and millimeters, but can also determine the velocity of the material under test.

5.4.11.1 Thickness Measurement Applications. Examples of applications for ultrasonic thickness measurement are as follows:

- Checking part thickness when access to the backside is not available.
- Checking large panels in interior areas where a conventional micrometer cannot reach.
- Maintenance inspections for checking thickness loss due to wear and/or corrosion.

5.4.11.2 General Principles. Two basic methods of measuring thickness ultrasonically are the pulse-echo method and the resonance method.

5.4.11.2.1 Thickness Measurement With the Pulse-Echo Method. The pulse-echo method is now the most commonly used ultrasonic thickness measurement method. This method uses the basic principle defined by the following equation:

d = vt

Where:

d = distance (inches)

v = velocity (inches per second)

t = time (seconds)

5.4.11.2.1.1 The ultrasonic instrument is capable of measuring time between the initial front and back surface signals or between successive multiple back reflection signals. Since the velocity for a given material is a constant, the time between these signals is directly proportional to the distance (thickness). Calibration procedures are used to obtain a direct readout of test part thickness. The accuracy depends on the surface condition, the transducer, and the instrument. On smooth surfaces (63-microinches or less), accuracy of ±0.001-inch, or better, can be obtained on the lower ranges of some digital-readout instruments. Readout resolution is usually 0.001 inches. On other ranges, ±0.5-percent of full scale is a typical accuracy.

5.4.11.2.2 Resonance Technique. Resonance equipment has been largely replaced by pulse-echo equipment for thickness measurement. This technique uses an instrument which applies continuous (as opposed to pulsed) electrical energy to the transducer. The frequency of this energy is continuously changing; therefore, the wavelength of the sound transmitted by the transducer is continuously changing too, but it is changing inversely in proportion to the velocity of the material being tested (l = v/f). When the transducer is coupled to a test part, and when one of the transmitted wavelengths is a multiple of the thickness of the part, the piezoelectric element in the transducer vibrates with higher amplitude. When this occurs, the transducer is said to be in resonance with the part. If the instrument is calibrated on a reference standard so that the peaks in the transducer element vibration amplitude correspond to known reference thicknesses, the instrument will indicate unknown thickness of a test part.

5.4.11.3 Thickness Measurement Correlation Factor. As discussed earlier, reference standards are required to calibrate the instruments prior to thickness inspection. If reference standards of a different material or heat treat condition are used, the resultant thickness readings SHALL be corrected by a correlation factor. The correlation factor is located in (paragraph 5.7.8).

5.4.11.3.1 Flat surfaced reference standards MAY be used for measurements on convex radii of curvature as small as 1-inch and concave radii of curvature as small as 3-inches. Test parts with radii smaller than 1-inch convex or 3-inches concave, require reference standards with curved surfaces and radii equal to the test part radii, ±10-percent. In addition, shoes are required (paragraph 5.3.4.1) and (paragraph 5.3.4.2).

5.4.11.3.2 The surface finish of reference standards SHOULD be 63-microinches or better if maximum accuracy is to be obtained. Surface roughness introduces errors as shown in Table 5-7.

5.4.11.3.3 The thickness of reference standards SHALL be measured by mechanical or optical means. Unless otherwise specified, the maximum tolerance for these measurements SHALL be ±0.001 inch or ±0.1% of the thickness, whichever is greater.

5.4.11.3.4 If there are two or more areas of different thickness on the test part within the limits of paragraph 5.4.11.3.3, which can be measured both ultrasonically and mechanically, or optically, these areas MAY be used as the standards.

5.4.12 Calibration and Thickness Measurement. Accurate thickness measurements require the reference standards and the test part, to have equal temperatures, within 10° F. Calibration SHALL be performed in the same physical location as the measurements on the test part. Adequate time SHOULD be allowed for the reference standard to reach the test part temperature. The horizontal linearity of the test equipment is crucial, and must be checked prior to calibration and any thickness measurement. Follow detailed instructions for performing thickness measurement with the specified ultrasonic instrument by consulting the specific instrument manual or TO 33B-1-2.

SECTION V ULTRASONIC INSPECTION INTERPRETATION

5.5 INTRODUCTION.

5.5.1 Evaluation of Discontinuity Indications. When a discontinuity indication is found, it is desirable to learn as much as possible about the discontinuity (or discontinuities). Information on the location, size, orientation, and spacing helps in determining the seriousness of a discontinuity.

5.5.1.1 Discontinuity Location. The location is determined by noticing the position of the indication on the waveform display and comparing this position to the positions of indications from known reflectors, such as the front and back surface. This is simple for straight beam inspections and is explained in paragraph 5.4.5. For angle beam inspections, the position is determined by first determining the angle of the refracted beam and then performing a distance calibration. With this information, the beam path and distance to the discontinuity in the test part can be determined. It is often helpful to use a cross-sectional sketch of the test part and draw the beam path on the sketch. For surface wave inspections, the location of a discontinuity is easily determined by wetting a finger with couplant, and then moving the finger along the test part surface away from the transducer. The surface waves will be damped by the wet finger, and the discontinuity signal will be reduced in amplitude until the finger moves just past the discontinuity. By noting when the discontinuity signal first starts to increase in amplitude, the location of the discontinuity is determined. A distance calibration can also be easily set up for surface waves. The transducer is placed on the test part at a known distance away from a reflector, such as an edge of the test part, or the transducer can be placed at a known distance from a reflector on the IIW block.

5.5.1.2 Discontinuity Size. The size of a small discontinuity (less than the diameter of the sound beam) is estimated by measuring the maximum signal amplitude produced by the discontinuity. Information on sound beam diameter (beam spread) is contained in (paragraph 5.2.6.5). In general, the amplitude from a small discontinuity is proportional to the cross-sectional area of the discontinuity, if the discontinuity is oriented normal to the sound beam. Since natural discontinuities usually have irregular shapes and rough surfaces, determination of the actual size of small discontinuities in general MAY NOT be possible with ultrasonics. Therefore, estimating the size of small discontinuities by comparing their signal amplitude with the signal amplitude of reference standard discontinuities is subject to errors. When making such comparisons (only to be used for rough estimates), the transfer technique SHOULD be used (paragraph 5.4.9). If, after applying transfer, the test part discontinuity signal is as large or larger than the signal from the reference standard discontinuity, it can be concluded the test part discontinuity is at least as large as the reference standard discontinuity. The transfer technique adjusts for differences in material attenuation, not for differences in discontinuity surface irregularities. Estimating the size of discontinuities larger than the sound beam is done by moving the transducer over the discontinuity, and mapping the extremities of the discontinuity. The outer edges of a discontinuity can be estimated by noting the positions of the center of the transducer when the signal amplitude from the discontinuity is reduced to 1/2 its peak value. This procedure estimates the projected area of discontinuities in a plane perpendicular to the incident sound beam.

5.5.1.3 Discontinuity Orientation. In evaluating discontinuities, it is helpful, if possible, to evaluate the discontinuities from several different directions. This can be accomplished by using a combination of angle, and straight beam methods, and/or sound entry from different surfaces. Inspecting in these various directions reveals more about the discontinuity. The direction where the highest amplitude signal is obtained is most nearly perpendicular to the plane of the discontinuity for equivalent distances. If the discontinuity signal changes very little with changing direction, the discontinuity is probably rounded. The sound scattered from a rounded discontinuity is independent of the incident direction. A flat discontinuity gives a maximum reflection when the incident sound beam is perpendicular to the discontinuity.

5.5.1.4 Discontinuity Spacing. Closely spaced small discontinuities can produce multiple indications often accompanied by the loss of back reflection. An example of how large grain size and/or porosity can produce multiple indications and reduce the amplitudes of back-reflection multiples is shown in (Figure 5-53). It is necessary to change the A-scan settings to check for both the effects, because the back surface signal probably saturates the display at the gain setting that shows the multiple indications. By lowering the gain and lengthening the sweep range, the decreasing amplitude of multiple back reflections is observed. The rate of decrease in the amplitudes of the back reflection signals will be greater than for an area with no discontinuities.

5.5.2 Types of Discontinuity Indications. Several different types of indications will be encountered in ultrasonic inspections. Some of these indications can cause confusion, resulting in false conclusions. It is important for the operator to be familiar with the ultrasonic system variables (paragraph 5.2.5 through paragraph 5.2.6.7) and the additional information below. This will help the operator in evaluating inspection results and avoiding erroneous conclusions.

5.5.2.1 Loss of Back Reflection and/or Multiple Indications. Loss of back reflection with no other indication can be caused by a number of factors such as the following:

- Large grain size
- Porosity
- Dispersion of precipitated particles in the material
- Overheated structure

5.5.2.1.1 However, these features could produce multiple indications (Figure 5-54). Lowering the frequency will generally reduce the multiple indications. When either multiple indications and/or loss of back reflection is noted, the test part SHOULD be compared with the reference standard using transfer in accordance with (paragraph 5.4.9). The results SHOULD be evaluated in accordance with the limits in (paragraph 5.4.9.4).

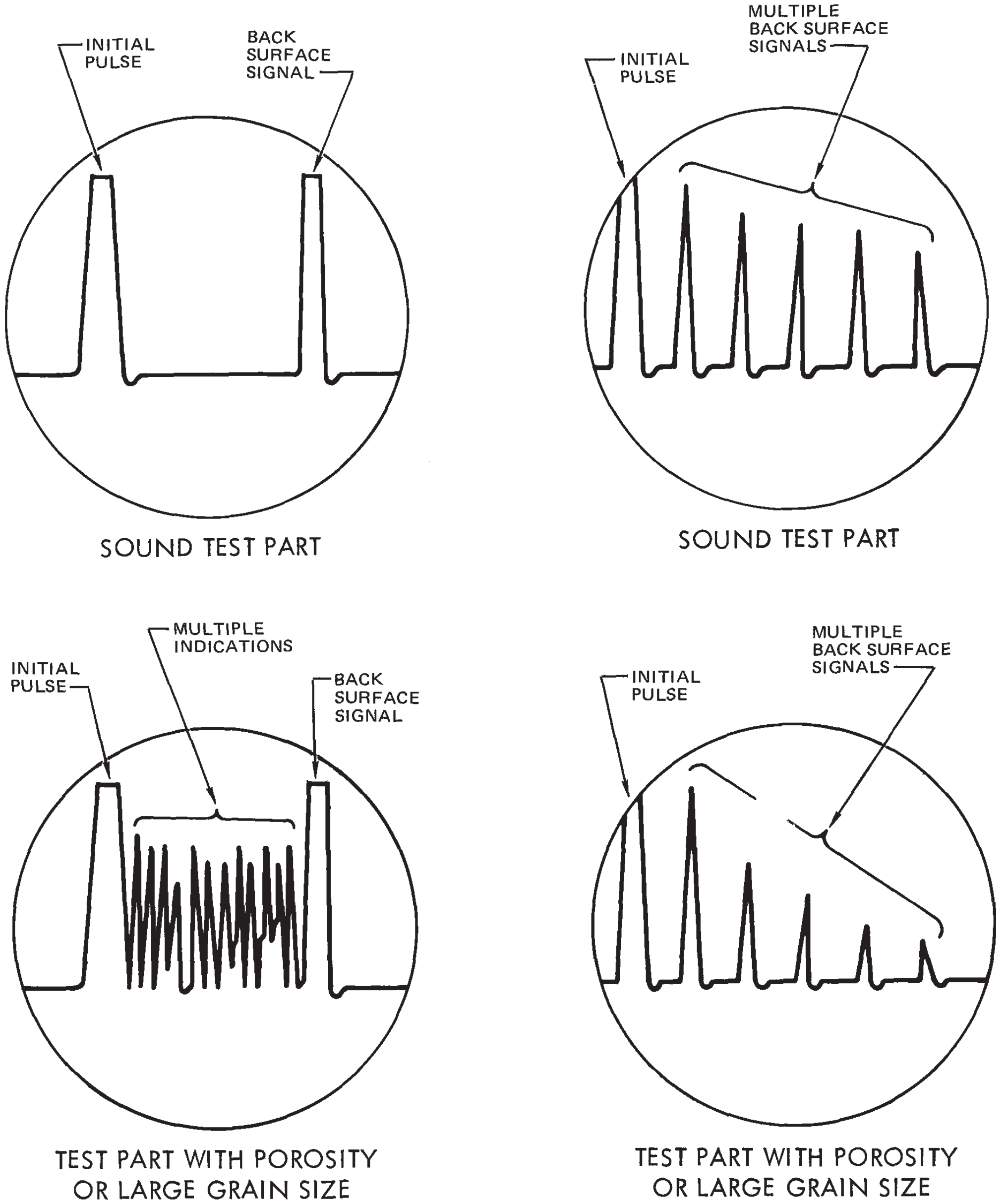


Figure 5-53. Example of Multiple Indications and Decrease in Multiple Back Reflections Caused by Large Grain Size or Porosity

5.5.2.2 Delaminations. When inspecting either metal parts fabricated from sheet, plate, or nonmetallic composite parts, delaminations can be detected by noting what appears to be a reduction in the distance between back reflection multiples as shown in (Figure 5-54). Actually, the signals indicate multiple echoes from the delamination instead of the back surface.

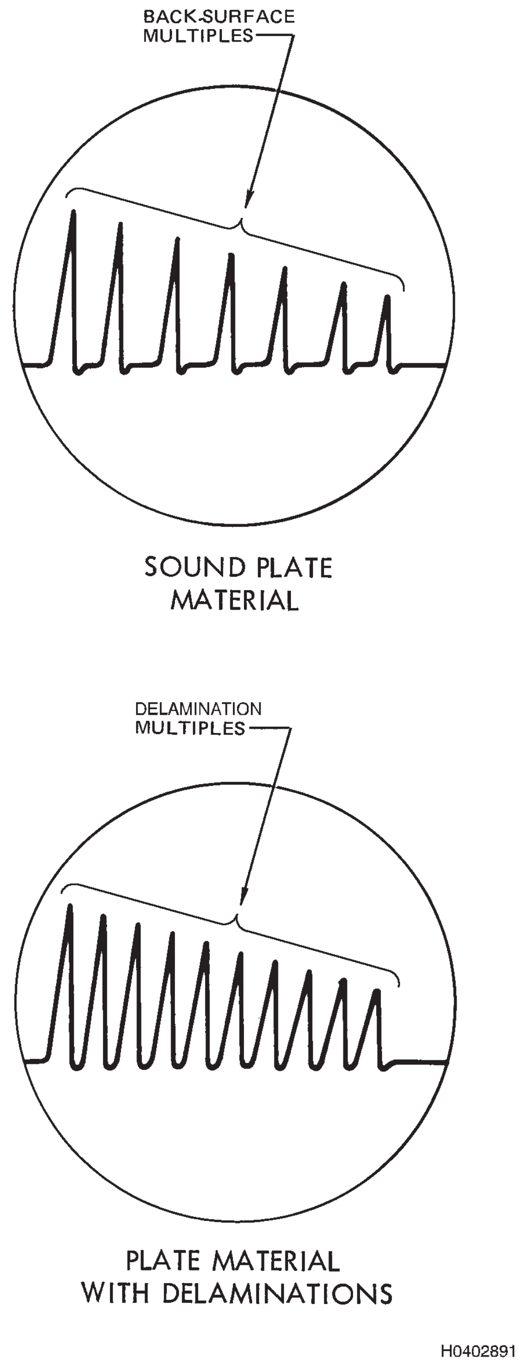


Figure 5-54. Effect of Delaminations in a Plate on Multiple Back Surface Signals

5.5.2.3 Surface Wave Indications in Straight Beam and Angle Beam Inspections. Due to the side lobe energy, surface waves can be generated when using straight beam transducers (Figure 5-11). Surface waves have also been observed in some inspections using angle beam transducer. These surface waves can cause signals from edges of the test part which can be mistaken for a discontinuity. These signals (Figure 5-55) are easily identified by varying the distance between the transducer and the part edge, and watching the signal move. The surface wave signal will move toward the initial pulse as the transducer is moved toward the edge.

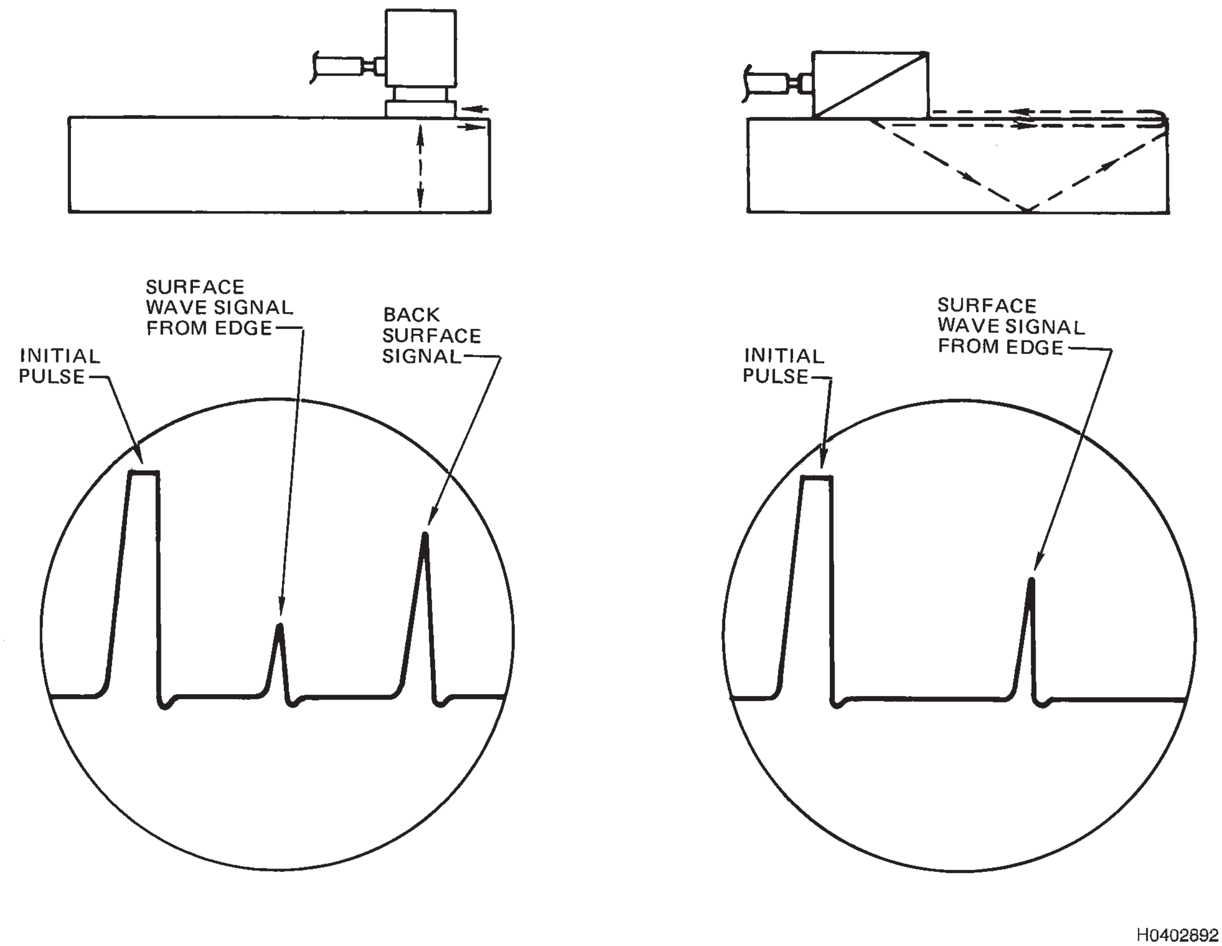


Figure 5-55. Irrelevant Surface Wave Signals

5.5.2.4 Parallel Boundaries. When using straight beam inspection near a boundary parallel to the sound beam axis, the spreading sound beam results in reflections and mode conversion at the boundary (Figure 5-10). These reflections from the boundary interfere with the main sound beam and can greatly reduce the sensitivity for detecting discontinuities close to or coming from the boundary. Such a case could occur when inspecting a bolt. As the transducer is moved closer to the boundary, the sensitivity is further reduced. When inspecting close to a boundary, it is therefore necessary to use a reference standard with the reference discontinuity located at the boundary. An example of such a discontinuity is a lateral saw cut (Figure 5-56). Flaws close to boundaries are better located by using, when possible, angle beam techniques (Figure 5-57).

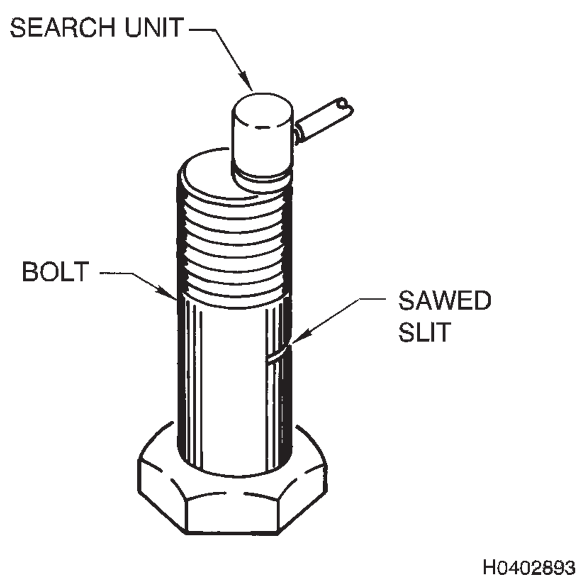


Figure 5-56. Reference Standard for Inspection of a Bolt

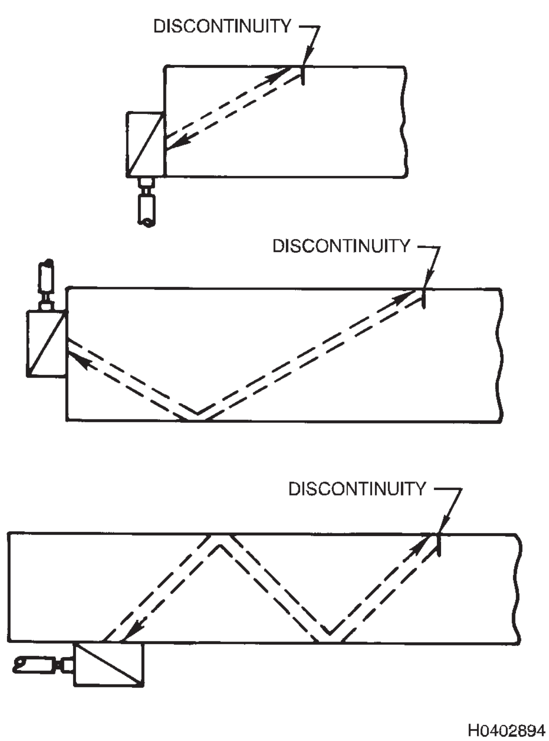


Figure 5-57. Angle Beam Technique for Locating Discontinuities at Boundaries

5.5.2.5 Loose Transducer Element. A transducer element can separate from the damping material in a transducer. This will cause the initial pulse to become a long ringing signal (Figure 5-58). Such a situation will cause the search unit to fail the dead zone test. When this happens, the transducer SHALL be replaced.

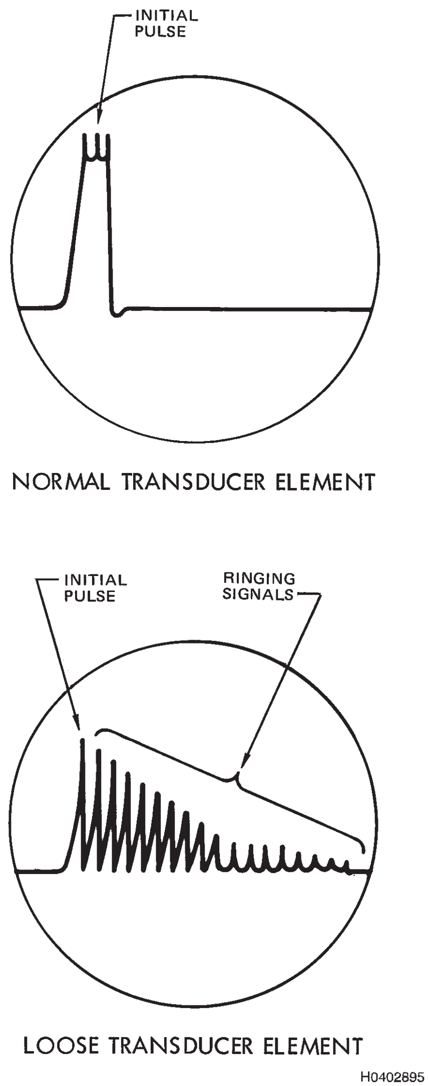


Figure 5-58. Example of Ringing Signals Due to a Loose Transducer Element

5.5.2.6 External Noise. Noise can be indicated on the waveform display when disturbances are created by such sources as follows:

- Nearby operation of electrical machinery or radio or radar transmitters.
- Machining on the test part (grinding, cutting, filing, etc.) during the inspection.
- Ground loop.

5.5.2.6.1 Noise from the causes listed above are more likely to be encountered when using equipment with a broadband receiver amplifier and/or long cables between the transducer and the instrument. Sometimes a double shield on the cable, as shown in Figure 5-59, will help reduce this noise. In this case, the ground electrode of the transducer element is not connected to the metal case of the transducer, and the external shield of the connecting cable. The ground electrode is connected to ground via a second internal shield of the cable. Ground l grounded but also for safety reasons. If a ground loop is suspected, tie all grounds together, and connect them to a good earth ground. Portable a/c units can be operated, with constant voltage transformers, and if electrical interference on the a/c circuit is suspected, special transformers are available to block such interference.

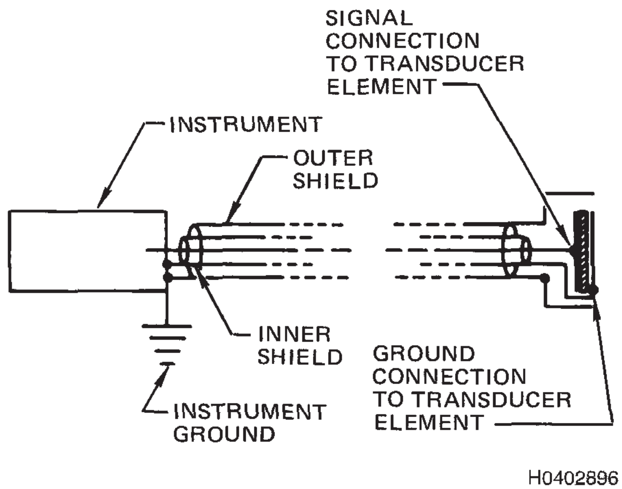


Figure 5-59. Double Shield for Reducing External Noise Signals

5.5.3 Test Part Variables.

5.5.3.1 Surface Condition. Rough surfaces and surfaces with loose or pitted paint, scale, or corrosion, may distort ultrasonic inspection results, preventing a meaningful inspection due to scattering of the sound beam and/or poor coupling. This can cause:

- Insufficient ultrasonic energy reaching discontinuities within the part.
- Loss of resolving power due to an increase in the length of the dead zone caused by a lengthening of the front surface echo. This is caused by reflections of side lobe energy. On smooth surfaces, the side lobe energy is not normally reflected back to the transducer; and therefore, does not interfere with inspection.
- Beam divergence, or widening of the sound beam within the test part.

5.5.3.1.1 To minimize these effects, the sound entry surface and the back surface of a test part SHALL be free from loose, heavy or uneven scale, machining/grinding, or other loose foreign matter.

5.5.3.2 Geometry of the Part. The position and shape of the sides and back wall of the part can affect the test. A back surface not parallel to the front surface can result in internal mode conversion and cause confusing indications or complete loss of back reflection. It is important the inspector be familiar with the part geometry prior to inspection.

5.5.3.3 Flat Sound-Entry Surfaces. In the case of test parts with parallel front and back surfaces, it is often required to monitor the back reflection signal in order to evaluate the material and/or assure ultrasonic energy is passing through the part. Any loss of back reflection MAY be cause for rejection, unless it can be shown that the loss of back reflection is due to a non-parallel back surface or back surface roughness. If back surface roughness is found to be the cause of the back reflection loss and cannot be eliminated, the entire test item SHALL be inspected with another technique to assure conformance to the applicable specification or test procedure.

5.5.3.4 Curved Sound-Entry Surfaces. If the test specimen surface is curved beyond certain limits, a plastic shoe is required to match the transducer face to the curved surface (paragraph 5.3.4).

5.5.3.4.1 Concave and Convex Surfaces. For a concave surface, the sound beam tends to be focused as it passes into the test part (Figure 5-60). Depending on the depth in the part, discontinuity signals can be increased in amplitude over signals received from an equivalent discontinuity in a part with a flat sound entry surface.

5.5.3.4.1.1 For a convex surface, the acoustic power that reaches an internal discontinuity is reduced by refraction at the test surface (Figure 5-61). Signals received from a discontinuity have less amplitude than signals received from the same size discontinuity in a test specimen with a flat sound entry surface.

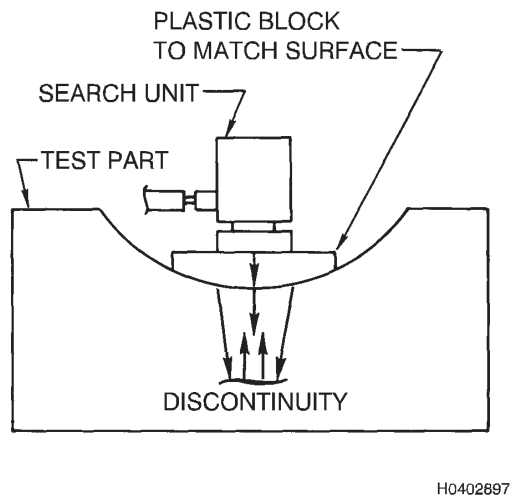


Figure 5-60. Concave Sound Entry Surface

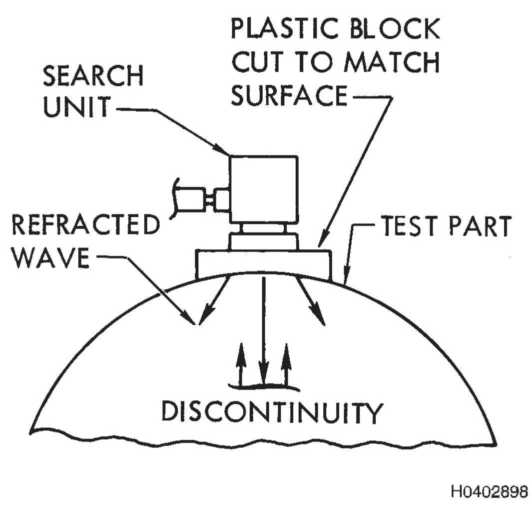


Figure 5-61. Convex Sound Entry Surface

5.5.3.4.2 Because of the variation in a signal due to curved surfaces, it is best to have a curved surface reference standard for setup of the test. The curved surface of the reference standard SHOULD be similar to the curved surface of the test part. Specifically, when performing straight beam inspection on curved surfaces of cylindrical or irregularly shaped products, special ultrasonic test blocks containing specified radii of curvature and flat-bottom holes of standard diameter, may be required. For inspecting parts with convex surfaces or radii up to 4-inches (8-inch diameter), blocks conforming to the applicable specification or procedure SHALL be used. For parts with convex radii over 4-inches, use standard flat face blocks. For more information see ASTM standout E-1315 for steel blocks (ultrasonic examination of steel with convex cylindrically curved entry surfaces.)

NOTE

When shoes are fabricated from the same material as the test part, the sound will propagate straight into the test part. Refraction does not occur because the velocity in the shoe equals the velocity in the test part. For immersion techniques, no shoe is required, but refraction will be greater than illustrated in Figure 5-60 and Figure 5-61.

5.5.3.5 Internal Mode Conversion. A frequently misinterpreted form of mode conversion found in the field is shear wave converted to longitudinal. For example, on an H-3 sleeve and spindle inspection using a 45 ° transducer to inspect a large radius or bore, a non-relevant indication occurs in the area of interest as a result of this conversion (Figure 5-62). At a certain transducer position, part of the shear wave will convert to longitudinal as it reflects from the bore. This longitudinal wave (paragraph 5.2.3.1) will travel at double the velocity of the shear wave and will be reflected to the surface, then back to the bore. It then returns to the transducer to cause a non-relevant indication similar to a crack indication. In this case, finger damping the part surface where the longitudinal wave reflects off of the part surface in front of the transducer will identify the indication as non-relevant.

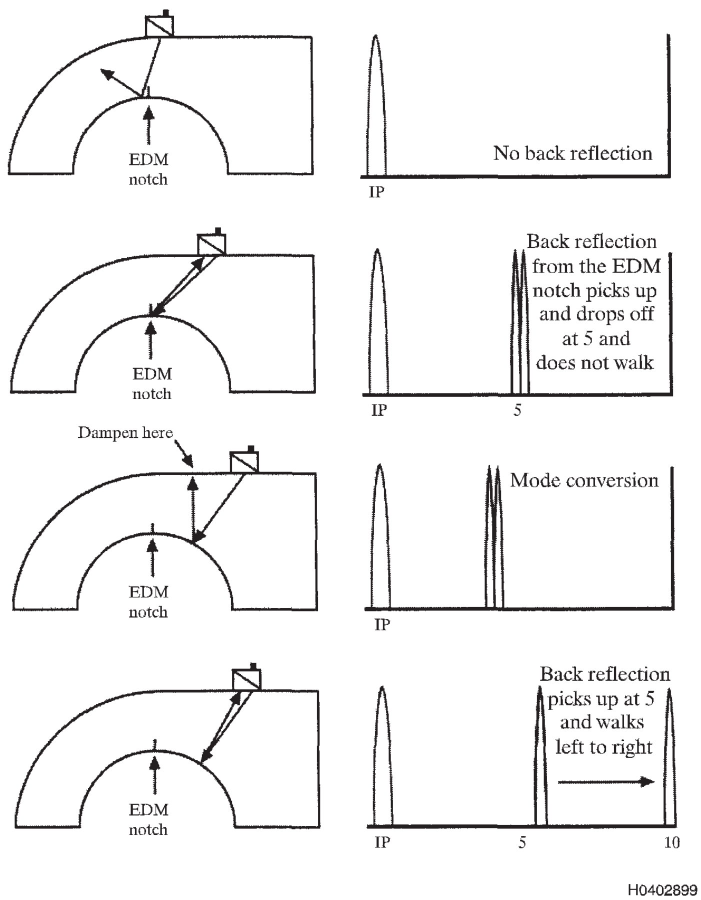


Figure 5-62. Example of Mode Conversion

5.5.3.6 Internal Structure. Discontinuities inherent in the test article, such as grain boundaries, affect the ultrasonic test by scattering the ultrasonic energy. This reduces the energy available for finding detrimental discontinuities and causes "noise" in the waveform presentation. Effects on an inspection increase as the frequency is increased and are most noticeable in materials with relatively large grain size. In certain applications, the loss in ultrasonic energy caused by internal scattering can be measured to evaluate metallurgical structures.

5.5.4 Discontinuity Variables. Ultrasonic beams can be reflected at various angles at the discontinuity interface; and can also spread or focus depending on the shape of the discontinuity.

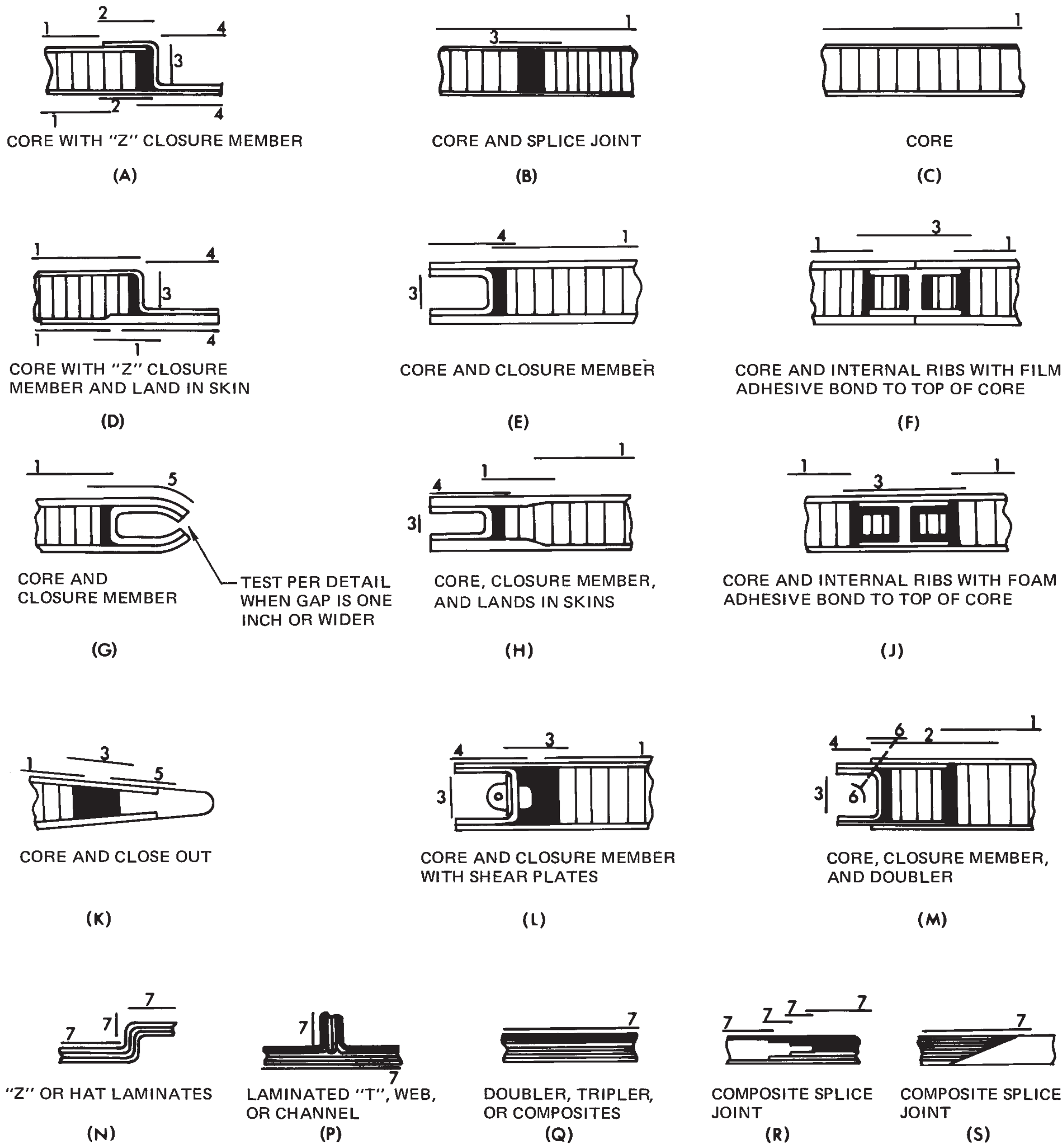
5.5.4.1 Size and Shape. When discontinuities smaller than the sound beam are oriented with one surface perpendicular to the incident sound beam, the amplitude of a reflected ultrasonic beam from a discontinuity increases as the area of the surface normal to the incident sound beam increases. An irregularly shaped or round discontinuity reflects sound energy at many angles, thus resulting in a loss of sound energy back to the transducer. Discontinuities that are flat and perpendicular to the sound beam will reflect the greatest amount of sound energy back to the transducer.

5.5.4.2 Orientation. Discontinuities with surfaces oriented at angles other than perpendicular to the sound beam reflect only a portion (if any) of the sound beam back to the transducer. Consider utilizing an angle beam inspection or employing a straight beam inspection from another surface if discontinuities are suspected to be located at angles other than parallel to the entry surface. To help in detecting discontinuities oriented at angles to an incident straight beam, it may be helpful to monitor the back surface reflection. A sudden decrease in back reflection when scanning could indicate a discontinuity or possibly a number of small discontinuities. If a discontinuity signal is observed which is proportional to the loss in back reflection, the discontinuity is probably flat and oriented normal to the incident sound beam. If the discontinuity signal is small in relation to the loss of back reflection signal, the discontinuity is probably turned at an angle to the incident sound beam or is rounded. A decrease in back reflection accompanied by multiple discontinuity signals or a general increase in the noise level MAY indicate the presence of multiple discontinuities.

5.5.4.3 Acoustic Impedance. The acoustic impedance of the discontinuity material in relation to the acoustic impedance of the test part is important. The reflections from an air interface such as a crack or void are large due to the acoustic impedance ratio. If a discontinuity had acoustic impedance close to the acoustic impedance of the test material, the acoustic impedance ratio would be small and very little reflection would occur. When an ultrasonic beam strikes a boundary between two different materials, part of the energy is transmitted to the second medium and a portion is reflected. The percentage of sound energy transmitted and reflected is related to the ratio of the acoustic impedances of the two materials. The acoustic impedance calculation is shown in (paragraph 5.7.7).

5.5.4.3.1 Determining Reflected Energy at an Interface. Acoustic impedance can be used to calculate the theoretical reflected and transmitted energy for an interface. The greater the difference in acoustic impedance across the interface, the greater amount of sound reflected. The theoretical reflection at a water-steel interface is 88-percent; at a water-aluminum interface it is 72-percent; however, the actual reflection often differs significantly from the calculated theoretical reflection. Surface roughness is one of the variables besides acoustic impedance that affects the percentage of reflection. The acoustic impedance of the discontinuity material in relation to the acoustic impedance of the test part is important. The reflections from an air interface, such as a crack or void, are large due to the acoustic impedance ratio. If a discontinuity had acoustic impedance close to the acoustic impedance of the test material, the acoustic impedance ratio would be small and very little reflection would occur. The formula used to determine the amount of reflected energy that occurs at an interface is located in (paragraph 5.7.7.1).

5.5.5 Inspection Coverage of Bonded Structures. Examples of bonded structures, along with suggested inspection coverage, is shown in (Figure 5-63). The ultrasonic inspection methods applicable to the numbered coverage shown in the figure are listed in (Table 5-1). Due to access limitations, it will not be possible, in many cases to apply the inspections in all the areas shown. These coverages and associated methods are guidelines only. Details of inspection coverage and inspection methods for a particular assembly SHALL be obtained from the applicable NDI manual or the depot engineering activity.



NOTES:

1. THE NUMBERED LINES SURROUNDING EACH VIEW INDICATE THE SCAN PLANES. THE NUMBER ON EACH LIN IS USED TO DETERMINE THE ACCEPTABLE INSPECTION METHODS BY REFERRING TO TABLE 5-1.
2. WHERE SURFACES ARE SYMMETRICAL, THE COVERAGE ILLUSTRATED SHALL BE CONSIDERED TYPICAL FOR BOTH SIDES.
3. SHADED AREAS (■) REPRESENT FOAM ADHESIVE.
4. WHEN THE SAME METHOD(S) ARE SPECIFIED IN MORE THAN ONE SCAN PLANE, CALIBRATION SHALL BE VERIFIED FOR EACH PLANE.

H0402900

Figure 5-63. Bonded Structure Configurations and Suggested Inspection Coverages

Table 5-1. Ultrasonic Inspection Techniques for Bonded Structures

Scan Line Number	Applicable Methods	
1	Near-Side Skin-to-Core a. Pitch/Catch b. Mechanical Impedance Analysis c. Resonance d. Eddy-sonic e. Through-transmission f. Pulse-echo g. Ringing	Core Damage a. Mechanical Impedance Analysis b. Through-transmission c. Pulse-echo Far Side Skin-to-Core a. Mechanical Impedance Analysis b. Through-transmission
2	Near-Side Skin-to-Core a. Resonance b. Mechanical Impedance Analysis c. Through-transmission d. Ringing Core Damage a. Mechanical Impedance Analysis b. Through-transmission	Far-Side Skin-to-Core a. Mechanical Impedance Analysis b. Through-transmission
3	a. Resonance b. Mechanical Impedance Analysis	c. Ringing
4	a. Resonance b. Ringing	c. Through-transmission d. Ringing
5	a. Resonance	b. Ringing
6	a. Through-transmission (with fluid delay lines)	
7	a. Resonance b. Mechanical Impedance Analysis	c. Through-transmission d. Ringing

5.5.6 Inspection Methods for Bonded Structures. Ultrasonic bond inspection techniques, along with advantages and limitations of each technique, are provided in (Table 5-2). Additional information on each technique is provided in the following paragraphs.

Table 5-2. Ultrasonic Inspection Techniques for Bonded Structures

	Inspection Method			
	Through Transmission	**Pulse-echo**	**Ringing**	**Damping**
Advantages	Applicable to structures with multiple layers, with or without honeycomb. Detects disbonds between any layer or in honeycomb. Detects small defects (larger than the diameter of receiving search unit).	Applicable to honeycomb structures with thick or thin skins. Detects small disbonds (search unit diameter and smaller).	Applicable to complex shapes. Detects small near-surface disbonds (larger than diameter of search unit).	Applicable to multi-layered structures with thick or thin sheets. Detects disbonds between any layers. Detects small disbonds (larger than diameter of search unit.
Limitations	Access to both sides of part required. Does not determine layer position of disbonds. Alignment of search units is critical. Couplant is required. Inspection rate is slow.	Inspection from both sides required. Does not detect far-side disbonds. Applicable only to honeycomb sandwich structures, usually those with single-layer skins. Couplant is required.	Applicable only to near-surface disbonds. Works best on disbonds between top sheet and adhesive layer, may miss disbonds on other side of adhesive. Works best on metals. Couplant required.	Applicable only to laminated (non-honeycomb) structures. Access to both sides is required. Does not determine layer position of disbond. Couplant is required.
	Resonance	**Pitch-Catch**	**MIA**	**Eddy-Sonic**
Advantages	Locates layer position of disbonds. Applicable to laminate or honeycomb structures. Applicable to complex shapes.	No couplant required, potential for faster scanning. Special displays make interpretation easier.	No couplant required. Can be used on irregular or curved surfaces. Most effective on honeycomb structures: skin-to-core disbonds and core defects.	No couplant required, potential for faster scanning.
Limitations	Inspection required from both sides of honeycomb structures. Couplant required.	Reduced effectiveness for disbonds greater than 0.80 inch below inspection surface. Access to both sides of honeycomb required. Probe is directional with respect to locating boundaries of disbonds.	Reduced effectiveness on purely laminated structures.	Works only on metals. Reduced effectiveness for disbonds farther from inspection surface and for low conductivity metals (titanium).

5.5.6.1 Through-Transmission Technique. The principle of this technique is shown in (Figure 5-64). Delaminations in either skin, disbonds between skin and core, and core damage prevent the transmission of sound to the receiving transducer. The minimum size flaw detected is proportional to the size of the receiving transducers. The received signal does not have to disappear completely to indicate a flaw. Any flaw large enough to lower the received signal noticeably can be detected. Care SHALL be taken to move both transducers in tandem; otherwise, misaligned transducers will generate false indications.

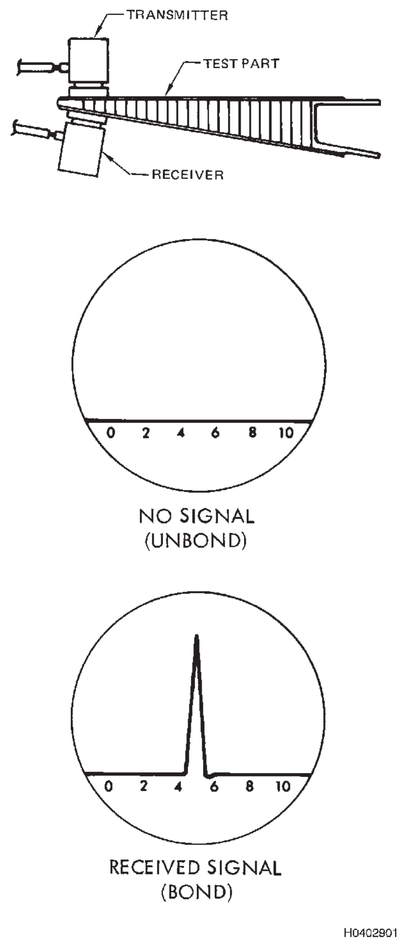


Figure 5-64. Through-Transmission Technique

5.5.6.1.1 Through Transmission Example. The structure is an aluminum honeycomb sandwich structure. Grids are marked on the surfaces to aid in maintaining transmitter/receiver alignment mapping boundaries of suspected flaws, assuring complete inspection coverage. The grid sizes are proportional to the critical flaw size of the respective zones. During the inspection one transducer is placed in the center of a grid square and the other is manipulated to maximize the received signal, as indicated in view B (Figure 5-65). Each square is inspected in turn. If the through-transmission signal falls below 50-percent of saturation, as indicated in view C (Figure 5-65), couplant and transducer alignment SHOULD be checked. If there is a definable area where the signal is less than 50-percent, mark the boundary (at the centerline of the receiving transducer) where the signal equals 50-percent according to the procedure in view D (Figure 5-66).

5.5.6.2 Pulse-Echo Technique. The basic principle of this technique is shown in Figure 5-67. It employs an angle beam transducer because straight beam transducers can produce multiple echo signals from the layers that would interfere with echo signals from the core. This method is applicable only to honeycomb structures and is best applied to structures with single-layer skins as indicated in detail C (Figure 5-63) when the through-transmission technique cannot be used. Straight beam transducers could provide better results on structures with multi-layer skins. This technique SHOULD be used as a backup to techniques associated with dedicated bond inspection instruments discussed below. Angle beam transducers producing refracted angles of 30° to 90° MAY be used. The angle selected SHOULD be the one that produces the maximum signal response from the back of the core.

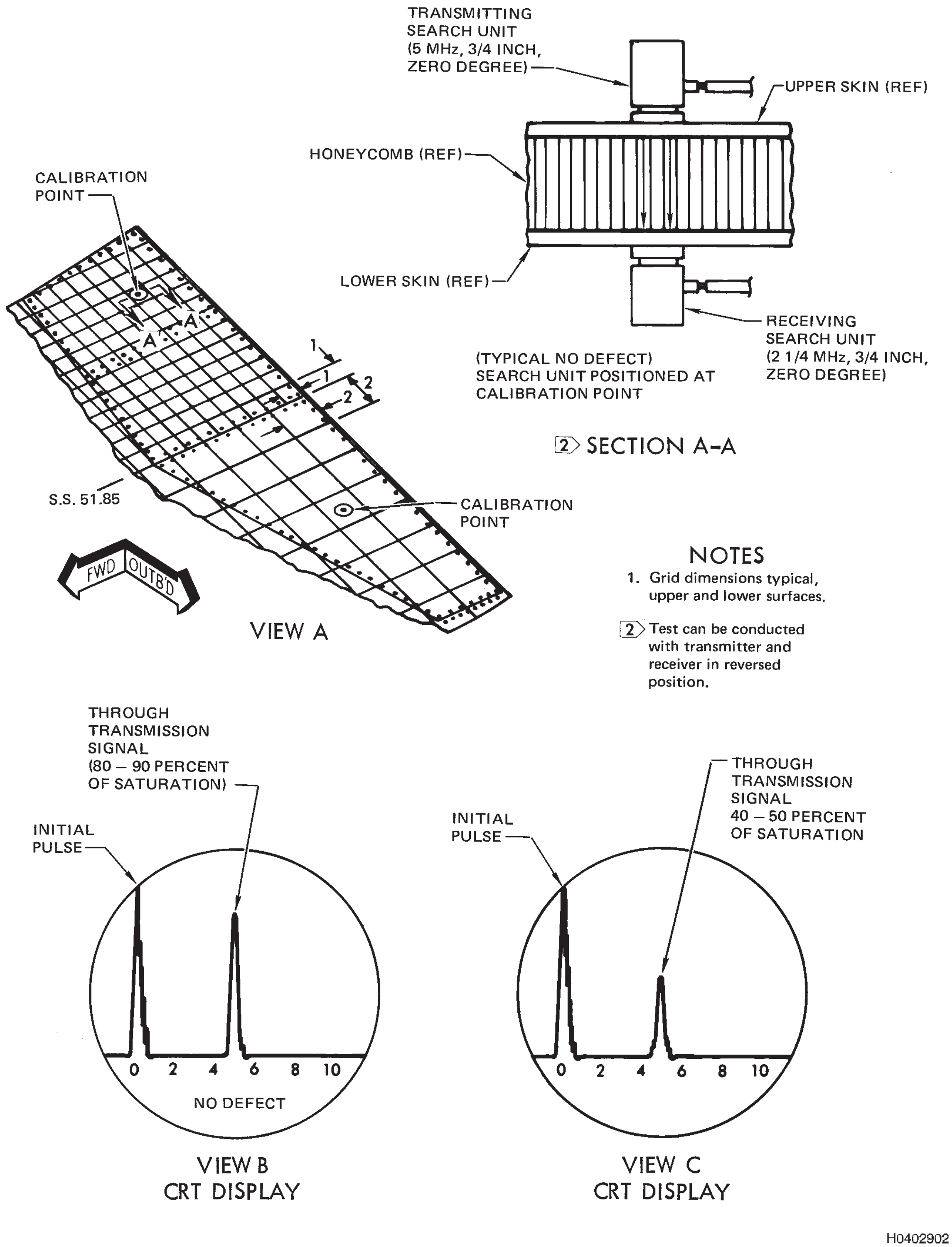


Figure 5-65. Procedure for Through-Transmission Inspection of a Stabilator View A - C

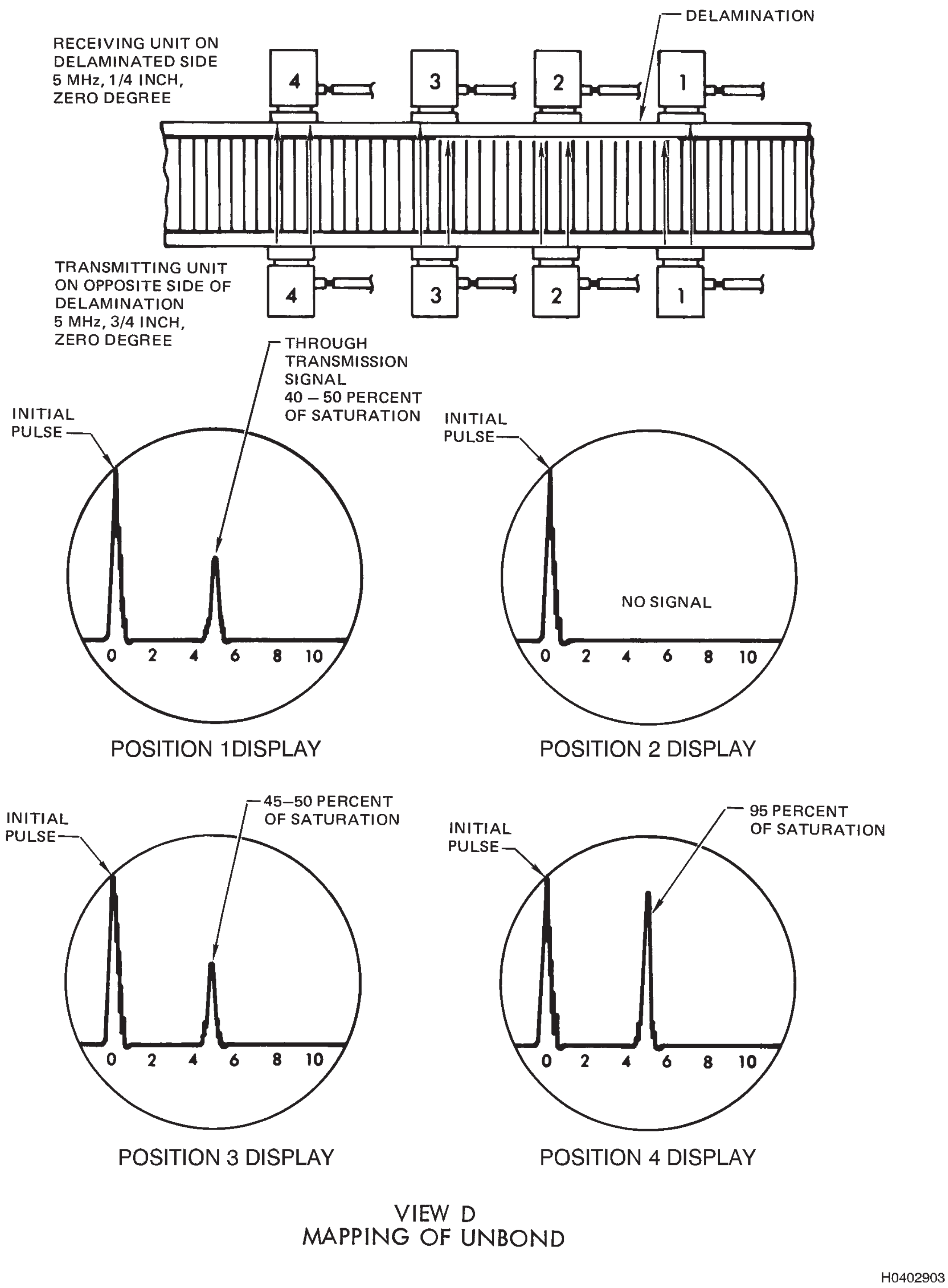


Figure 5-66. Procedure for Through-Transmission Inspection of a Stabilator View D

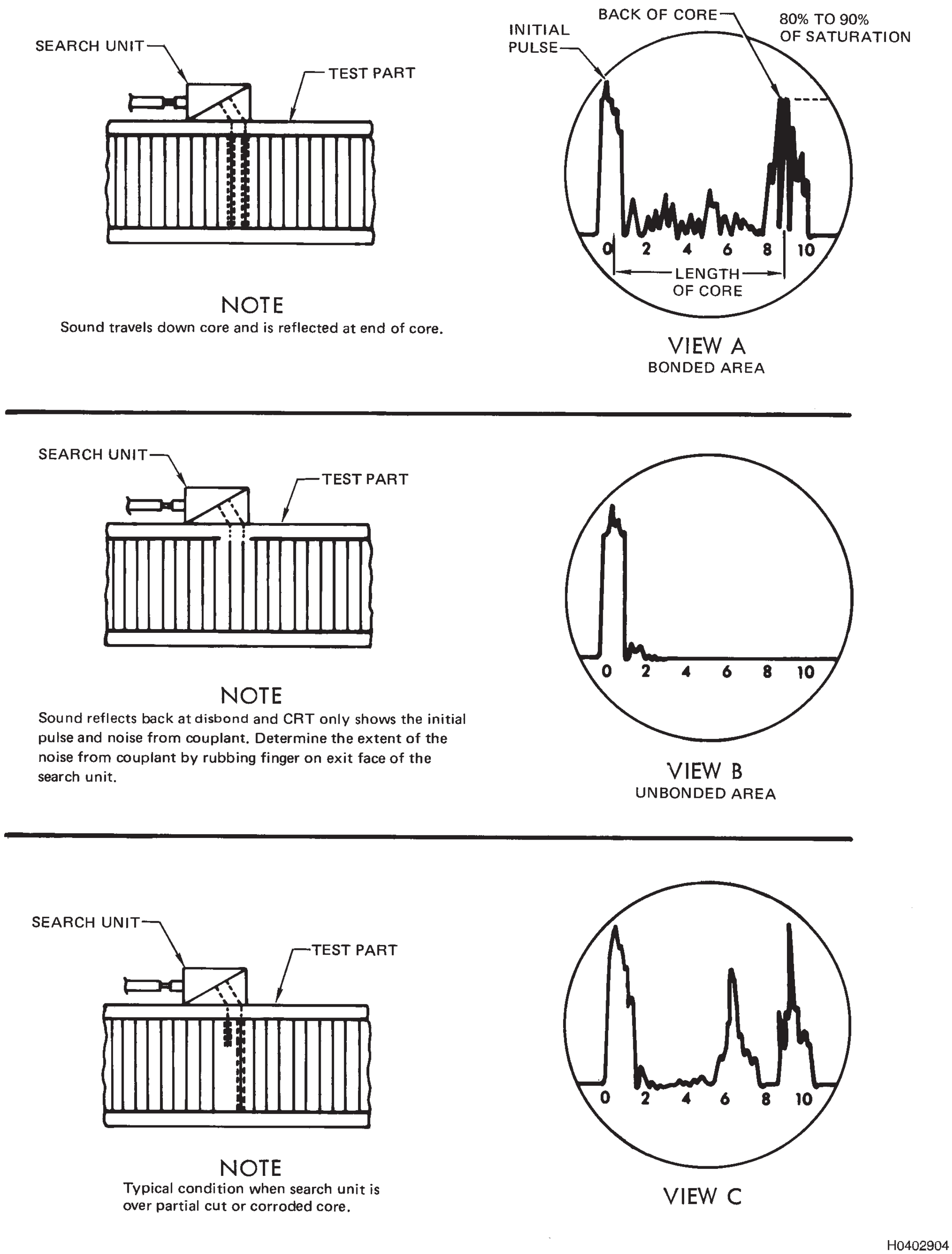


Figure 5-67. Pulse-Echo Technique

5.5.6.2.1 This technique can detect near-skin-to-core disbonds and broken or corroded core. Disbonds will cause a complete loss of the signal from the back of the core as indicated in view B (Figure 5-67). Broken or corroded core will reduce or completely eliminate the signal from the back of the core and can produce an echo signal as indicated in view C (Figure 5-67).

5.5.6.2.2 Indications MAY be mapped by marking the boundaries, where the back echo signal drops below 50-percent of the amplitude obtained in a good area (Figure 5-68).

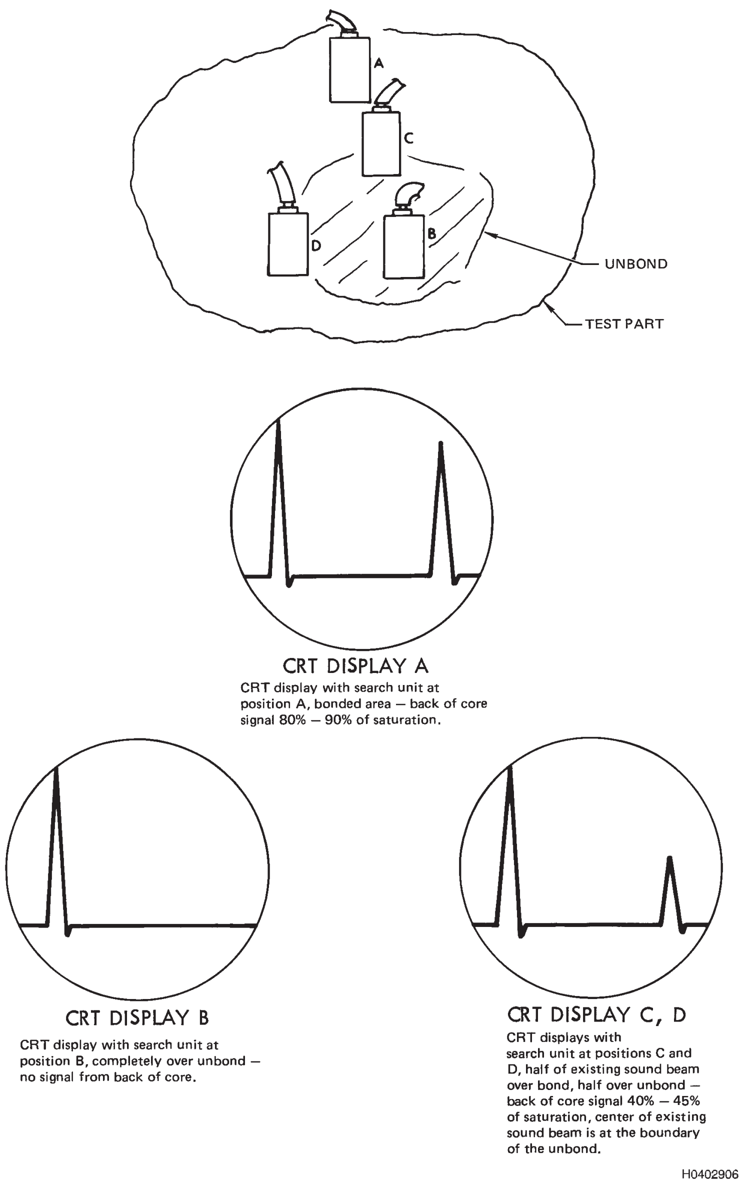


Figure 5-68. Mapping of Disbonds, Pulse-Echo Technique

5.5.6.3 Ringing Technique. The principle of this technique is shown in Figure 5-69. The A-scans in the figure represent the outline of multiple echo signals from the skin that cannot be individually resolved. This technique is most sensitive to disbonds between a single layer of skin and the adhesive layer. A disbond between the adhesive and the core, or another layer of skin or a doubler, will often not produce a ringing signal because the adhesive bonded to the top sheet dampens the signal.

Because of this limitation, it is recommended that this technique be applied only when one of the other techniques is not applicable. A good application for this technique is the inspection of core-to-closure-member bonds.

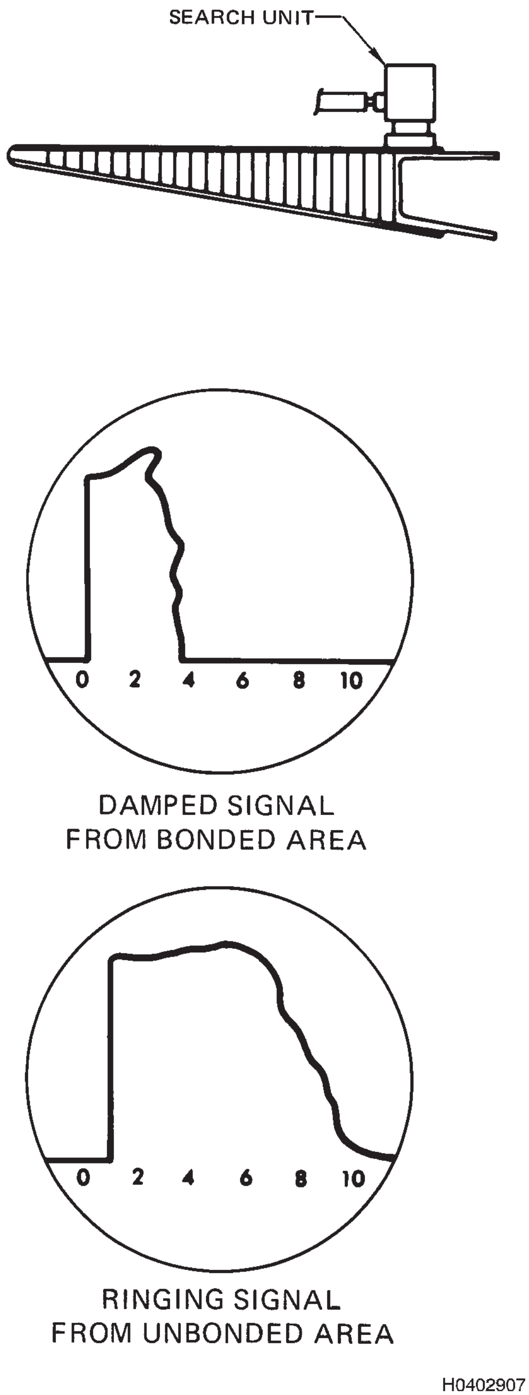


Figure 5-69. Ringing Technique

5.5.6.4 Damping Technique. When a finger, wet with couplant, is placed on the interface that sound is reflecting from the acoustic impedance ratio is altered causing the ultrasonic response to decrease in amplitude. As illustrated in Figure 5-70, as sound passes through the component to the backside of the of the component, the sound is reflected from the material-to-air interface. When an inspector places a finger wet with couplant at this location, the acoustic impedance ratio changes to material-to-water, thus more sound is passed THROUGH the interface resulting in a lower amplitude being displayed. When the inspector removes their finger from the interface, the acoustic impedance ratio returns to material-to-air, thus increasing the amount of sound that is reflected at the interface resulting in a higher amplitude signal being displayed. This technique is effective for laminate, doubler, and skin-to- closure-member bonds when access to the backside is available. If the inspector can dampen the multiple echoes from the far side of the bonded structure with a wet finger, then the bond is good. Otherwise, the sound is being reflected by a disbond and is not reaching the far surface, so it cannot be damped. Disbonds equal to or larger than the size of the transducer are easily detected.

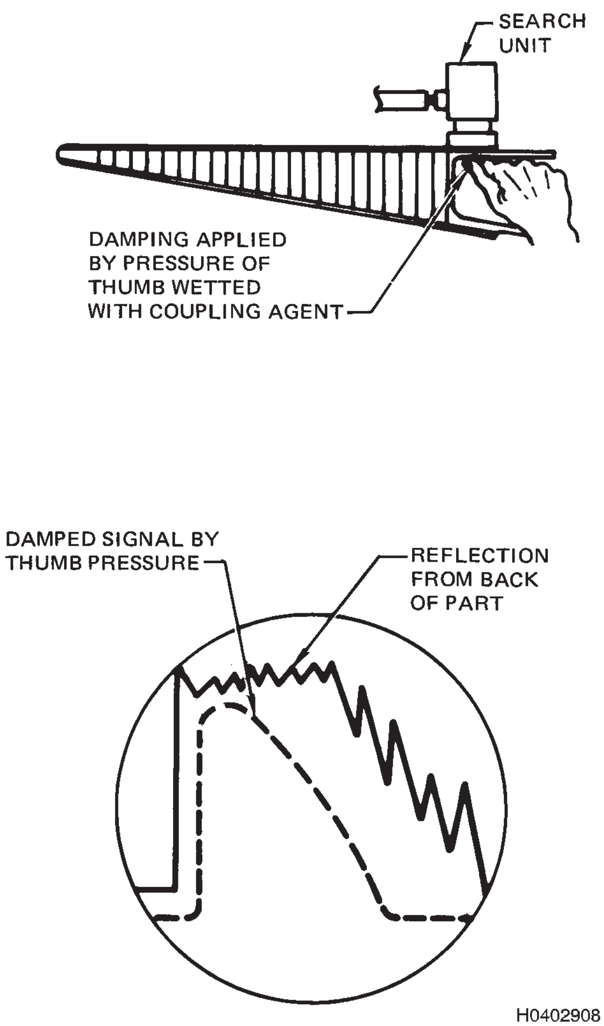


Figure 5-70. Damping Technique

5.5.7 Techniques Associated With Instruments Dedicated to Bond Inspection. Refer back to the bottom half of Table 5-2 for a summary of these methods, which are described in detail below.

5.5.7.1 Resonance Technique. When an ultrasonic transducer is placed on a test sample, with couplant, it is driven at its resonance frequency by an oscillator in the instrument. The detector in the instrument measures the phase and amplitude components of the electrical impedance of the probe, which are affected by changes in the acoustic impedance of the test part. The acoustic impedance of a part is altered by a lack of bond, commonly referred to as delamination. Bonded laminates act like a thin plate, which vibrates and generates a standing wave. Changes in the effective thickness caused by the delaminations will significantly affect the phase and amplitude of the acoustic wave in the part. With the resonance technique, the instrument indicates the probe's impedance with a "flying spot" on an ultrasonic impedance plane display. Amplitude changes in impedance are indicated by the radial distance of the "flying spot" from the center of the display (null reference point), and changes in the phase are indicated by the rotation of the flying spot around the center null point. An example of an ultrasonic impedance plane display (Figure 5-71) "A" shows the "flying spot" positions corresponding to different depths of disbonds (delaminations) in the bonded laminate in Figure 5-71 "B" The laminate is an example of a typical reference standard used for calibration. The positions can be gated, so a disbond produces an alarm, or the display can be monitored to determine between which layers a disbond occurs. The resonance mode works very well for detecting disbonds at metal-to-metal, metal-to-composite, and composite-to-composite interfaces, for finding delaminations within composite materials, and for detecting skin-to-core disbonds in honeycomb sandwich structures.

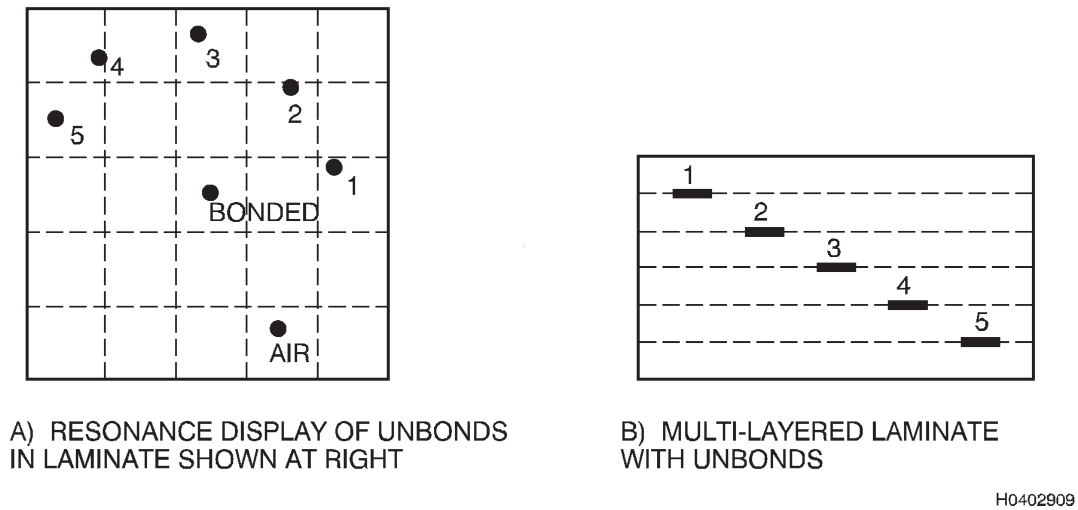


Figure 5-71. Resonance Method

5.5.7.2 Pitch/Catch Impulse Method. The pitch/catch method uses a pair of transducers displaced from each other by a fixed distance. The transducers are placed on the same or opposite sides of the part. A single ultrasonic frequency is transmitted into the part by one transducer; a second transducer in the same probe assembly receives the returned signal. Contact with the part is made through nylon wear tips on spring-loaded metal rods attached to the respective transducers. The ultrasound travels through the material between the two probe tips. Depending on the instrument, the received signals are displayed in various ways:

- Amplitude and phase components are displayed on separate meters.
- The resultant signal activates a light-emitting-diode (LED) display.
- The phase and amplitude components are combined to position a "flying spot" on an impedance plane display.

The display in Figure 5-72 shows a box in the middle of the display, which is the gate that sets off an alarm if the "flying spot" lands inside, indicating a disbond.

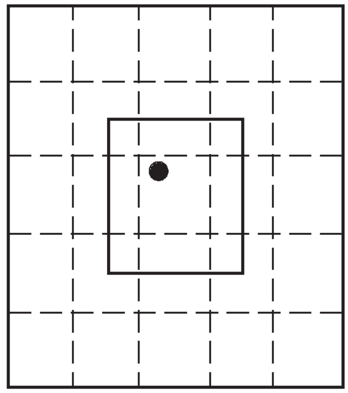


Figure 5-72. Impedance Plane Display of a Pitch/Catch Impulse Technique

5.5.7.2.1 The pitch/catch impulse probe is directionally sensitive, such that both active tips must be over the same condition of bond for unambiguous signal interpretation. For example, (Figure 5-73) shows the proper way to align the active tips for precise mapping of disbonds.

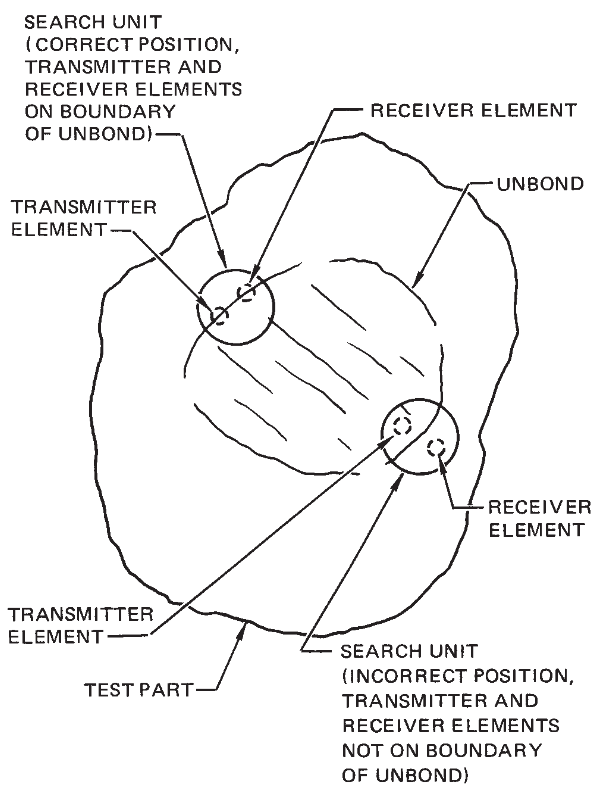


Figure 5-73. Pitch/Catch Probe Positions for Mapping Disbonds

5.5.7.2.2 Some pitch/catch instruments permit the operator to select the frequency, while in others the frequency are fixed. Typically, selectable frequencies range from 2.5 to 70 kHz; the frequency providing the largest received signal, due to maximum flexure in the layer being tested, is chosen for the inspection. A typical fixed frequency is 25 kHz. The low frequencies eliminate the need for liquid couplant between the transducer and the test part. On some instruments, a variable time gate is used to select the part of the received pulse that has the greatest change in amplitude when the probe is moved from a bonded area to a disbonded area. The amplitude will be larger over the disbonded area than a bonded area because the motion of the layer is restricted over a bonded area and energy is lost into the second layer. The pitch-catch mode works on composite delaminations, skin-to-core disbonds, and metal-to-metal disbonds. The technique tends to lose its effectiveness if the material thickness between the probe and the delamination exceeds 0.08-inch of aluminum or 0.30-inch of nonmetallic composite. In addition, the minimum dimension of a detectable flaw is greater than or equal to the probe tip spacing.

5.5.7.3 Pitch/Catch Swept Frequency Technique. Instead of a single frequency, each pulse contains a range of frequencies (e.g., 20 - 40 kHz or 30 - 50 kHz), generating ultrasonic Lamb (plate) waves within the part. These waves are attenuated by coupling into the second layer in well bonded joints. In a disbonded region, the waves travel with very little attenuation or leakage into the second layer and produce larger indications. Both the swept and impulse techniques will find similar types of defects; however, with the swept technique, calibration interpretation of the signals are easier because both the amplitude and phase signals are simultaneously displayed in the form of circular patterns on one X-Y active screen. Instrument displays corresponding to three situations detected with the Pitch/Catch Swept-Frequency Technique are shown in Figure 5-74.

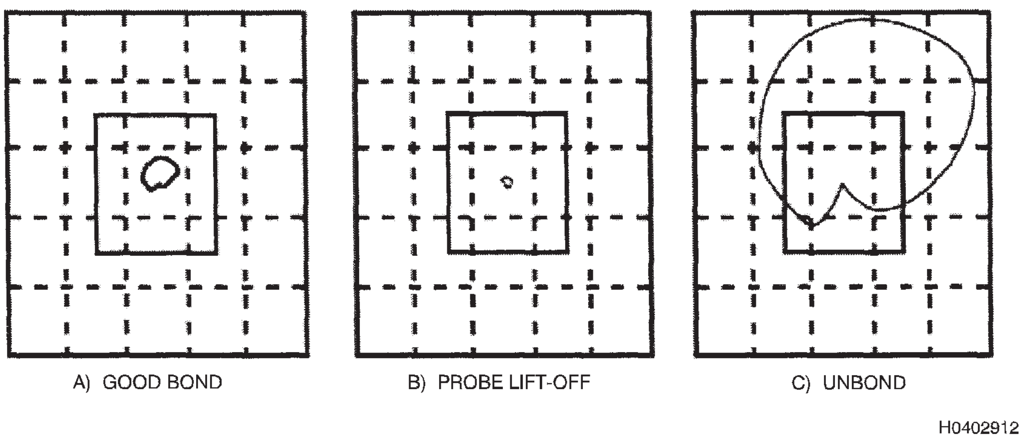


Figure 5-74. Pitch/Catch Swept-Frequency Signal Patterns

5.5.7.4 Mechanical Impedance Analysis (MIA) Technique. The driver portion of a single-tip dual-element probe generates low-frequency sound waves that transfer to mechanical movements in the test material. The stiffness and mass of the material are measured by the receiving sensor, and displayed in terms of both phase and amplitude values. The receiver element at the bottom of the probe has its loading affected by the part stiffness, which changes from very high over bonded regions to low over disbonded regions. Since the measurements are a comparison of stiffness, results are better on stiff structures. Flexible composites would not have much change in stiffness from bonded to disbonded areas. The MIA mode does not require couplant, and has a small contact area so it can be used on irregular or curved surfaces. The MIA technique seems most suitable for detecting damage associated with honeycomb core such as: skin-to-core disbonds, severely corroded aluminum core, and buckled or crushed core; additionally, disbonds and delaminations also can be detected with this technique. Typical positions of indications produced with the MIA technique are shown in Figure 5-75. During an inspection, only the "flying spot" would be present on the display. The gate box can be positioned anywhere on the display; the appropriate position is determined during calibration.

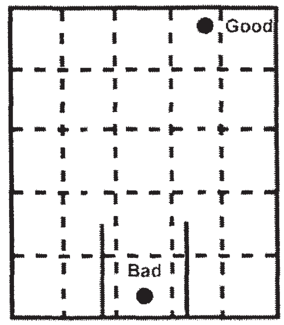


Figure 5-75. Mechanical Impedance Analysis Display

5.5.7.5 Eddy-Sonic Method.

CAUTION

Gradual changes in indications on an instrument display SHOULD be evaluated to see if the part thickness is changing. If the part thickness has changed, recalibration is required. When possible, scanning SHOULD be performed in directions of constant thickness.

Since this method is based on the generation of eddy currents in the test part, it will work only on metal structures. The instrument sends electrical pulses, with frequencies in the low kilohertz range, to a coil in the probe. The resultant pulsating magnetic field produces eddy currents in the part; the eddy currents cause the part to vibrate, and a microphone on the axis of the coil detects the sonic vibrations. Disbonds cause changes in the vibrations of the part. The detected changes produce an indication on a meter or an LED array. The probe usually has a mechanical lift-off adjustment that sets the air gap between the coil and the test surface to minimize the noise produced by probe scanning. This method works best on metallic honeycomb structures with thin skins (0.062 inch or less). Other methods do as well on such configurations, because the eddy-sonic is rather limited in its application, it is not commonly used.

NOTE

For a reliable bond inspection, the inspection surfaces of the test part SHALL be free of loose paint and foreign matter.

5.5.8 Thickness Measurement Test Part Preparation.

5.5.8.1 Surface Contamination. All foreign matter that might interfere with the thickness measurements SHALL be removed. Examples of such matter are loose scale, paint, dirt, and rust. For maximum accuracy, paint SHOULD be removed in the area to be measured. Paint can introduce errors in the measurements up to three times the maximum thickness of the paint. Metallic plating on the surface of the test part (Cr, Cd, Ni, etc.) will not significantly affect the accuracy of the readings; usually, this plating is relatively thin (0.0005-inch).

5.5.8.2 Surface Roughness. The surface finish of the test part affects the accuracy of the reading. If the surface of the test part is pitted or irregular, consistent readings will not be obtained. If permitted by the applicable weapons system manual or the prime depot engineering authority, local areas MAY be sanded to provide a smooth surface for increased accuracy in the thickness measurements.

5.5.9 Thickness Measurement Considerations.

5.5.9.1 Corrosion Pitting. The effect, corrosion pits on the back surface of the test part has on thickness measurements, depends on the size of the pits and the size of the search unit. The depth of large pits (the size of the search unit diameter or greater) can be measured by subtracting minimum readings from maximum readings obtained on adjacent areas of the test part. Smaller pits will generally cause a broadening of the back surface reflection signals, and sometimes a reduction in amplitude due to scattering of the sound beam. These effects can be observed on instruments equipped with waveform displays. Smaller pits also lower the average thickness readings of the test part.

5.5.9.2 Curved Surfaces. Measurements of curved surfaces require reference standards in accordance with paragraph 5.4.11.3.3. In addition, for convex radii less than 1-inch or concave radii less than 3-inches, shoes are required to adapt the search unit to the curved surface. Detailed procedures for taking the measurements SHALL be obtained from the applicable NDI manual or the depot level engineering activity. On all curved surfaces, it is recommended an instrument with a waveform display be used. Small-diameter transducers (1/4-inch or less) are also recommended. When making a measurement on a curved surface, the back surface signals SHOULD be maximized by rocking the transducer on the surface until the back surface signals peak and the thickness reading is at a minimum. The minimum thickness reading SHOULD be recorded as the test part thickness.

SECTION VI ULTRASONIC INSPECTION PROCESS CONTROLS

5.6 INTRODUCTION.

5.6.1 Ultrasonic Process Control Requirements. In the ultrasonic inspection process, like all other processes, you must know your equipment is functioning properly. Frequency of process control checks on equipment SHOULD come from the operations manual on the equipment. Frequency of transducer checks SHOULD be determined by the amount of use. The operator is the critical link in this process. Even if all the equipment is working properly, the inspector must follow the written procedure and use the correct standard. Deviations SHALL NOT be made without proper engineering authority. In this chapter, the terms "reference standard," "reference block," "test block," and "calibration standard" all have the same meaning as defined in the glossary. Reference standards are used by the instrument operator. Calibration of reference standards by laboratories is not required; however, to ensure uniform inspection sensitivity, reference standards SHALL be traceable to a “master standard” in terms of discontinuity response. Minimum interval frequency for process control checks on equipment and transducers are stated in TO 33B-1-2 WP 105 00.

5.6.1.1 Required Use. All inspections SHALL include the use of one or more reference standards for setting up an inspection. In addition, all discontinuity indications SHALL be compared to a reference standard by comparing the signal amplitude of the discontinuity with the signal amplitude of the reference standard. This is done either in percent signal amplitude, or by noting the difference in amplitude in decibels (dB) when the instrument is equipped with dB attenuation controls.

5.6.2 Reference Standard Configuration. A reference standard for metals MAY be a block containing a flat-bottom or side drilled hole with a known size, a machined slot or notch, or an actual test part or similar manufactured part with an actual or simulated discontinuity of known size. For composite parts, a reference standard SHOULD adequately simulate the ultrasonic response from the part as well as the response from the expected defect types. For inspections of metals, the following guidelines should be considered when designing an inspection and specifying or designing the appropriate reference standard.

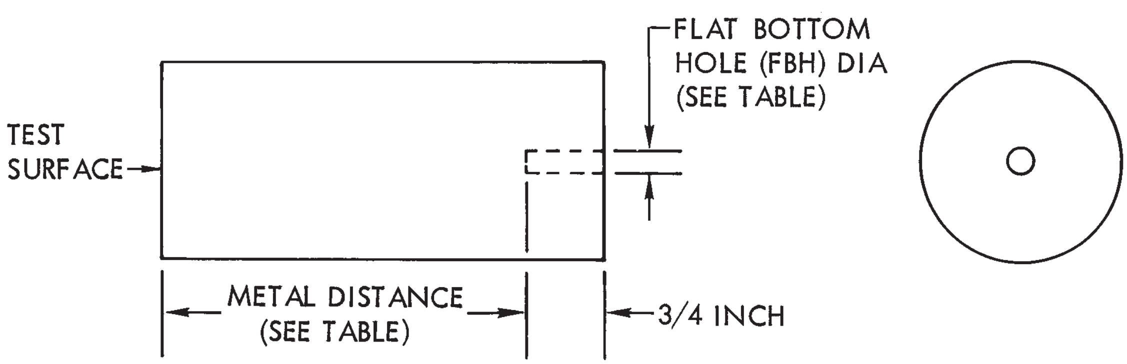
- ASTM standard practices E-127, E-428, and E-1158 should be followed when applicable.
- Curved surface reference standards MAY be required when performing straight beam inspection of curved entry surfaces on cylindrical or irregularly shaped products. Special ultrasonic test blocks containing specified radii of curvature, flat-bottom holes, EDM slots, or other simulated defects should be used. For parts with convex radii over 4-inches, use standard flat face blocks. Flat blocks MAY also be used to inspect other curved surfaces when supported by test data showing adequacy, with correction factors as applicable, and must be acceptable to the responsible engineering activity.
- International Institute of Welding (Type 2 IIW) blocks and/or miniature angle beam blocks SHALL be used as specified for determining certain characteristics of angle beam and straight beam transducers and MAY be used for distance calibrations. Refer to TO 33B-1-2 WP 105 00.
- Holes, notches, and other reflectors SHALL be protected against corrosion and mechanical defacing that would alter the ultrasonic echo signal. For example, it is recommended all holes be sealed to prevent corrosion of the holes, reflecting surfaces.
- For most inspections performed to locate cracks, an effective reference standard can be made by electrical discharge machining (EDM) notches. Notch dimensions must be verified before initial use. The notch of appropriate size SHOULD be placed in the expected location of cracks with the plane of the notch in the expected plane of cracks. Information on the expected location and orientation of cracks SHALL be obtained from the cognizant engineering authority. Other reflecting surfaces meeting the requirements of SAE AMS STD 2154 or ASTM E2375 are permitted. All standards SHOULD be clearly identified so that the material, hole or notch size, angles, and dimensions are clear.
- For some applications, like thickness measurement or back surface corrosion detection in metals; or delamination or disbond detection in composites, a known-thickness or known-good area on the part being inspection can serve as a calibration or reference standard.
- In some applications, in both metals and composites, where a suspect indication is being evaluated, the response from the same location on another identical aircraft can be useful as a reference specimen for response comparison.

5.6.2.1 Metal Travel Distance. The metal travel distance (distance from sound-entry surface to a discontinuity) for the test part and the reference standard must be the same within the tolerances shown in Table 5-3; or distance amplitude correction should be considered.

Table 5-3. Reference Standard Metal Travel Tolerances

Metal Travel Distance to Discontinuity in Test Part (inches)	Tolerances on Metal Travel Distance to Discontinuity in Reference Standard (inches)
Up to 1/4	±1/16
1/4 to 1	±1/8
1 to 3	±1/4
3 to 6	±1/2
Over 6	±10% of metal travel

5.6.2.2 Straight Beam Reference Standards. The ASTM test block configuration is shown in (Figure 5-76). Two sets of ASTM test blocks, one for aluminum and one for steel, are included in AS 455. Two ASTM specifications cover manufacturing and verification of these reference standards. They are ASTM E-127 (aluminum test blocks) and ASTM E-428 (steel test blocks). ASTM E-428 also allows the use of reference standards of other materials such as titanium. For more information see ASTM E-1158, "*Standard Guide for Material Selection and Fabrication of Reference Blocks for the Pulsed Longitudinal Wave Ultrasonic Examination of Metal and Metal Alloy Production Material.*"



METAL DISTANCE, INCHES	1/8	1/4	1/2	3/4	1-1/2	3	3	3	6	6
FBH DIA IN 64THS INCH	5	5	5	5	5	3	5	8	5	8

H0402914

Figure 5-76. ASTM Reference Blocks

a. When applicable, Table 5-4 MAY be used as an aid if the required flat-bottom hole, (FBH), reference standard is not available. The second column lists relative amplitudes of echoes from successive sizes of FBH's at the same metal travel distance. For example: the signal from a #5 FBH is 4 dB larger than the signal rom a #4 FBH, so the instrument gain would have to be decreased by 4 dB if a #4 FBH were available, but a #5 FBH was the required standard. If a #5 FBH were available, but a #2 FBH were required, the instrument gain would have to be increased 16 dB (7+5+4) for the inspection. A reference level (80%FSH) needs to be established for these equivalent transfers.

Table 5-4. Relative Signal Response from FBHs in ASTM Blocks

FBH Number (Size in 64ths of an inch)	Difference (dBs) From Previous FBH Size
2	
3	7
4	5
5	4
6	3
7	3
8	2

b. Hole bottoms are checked for flatness, and hole orientation is checked for perpendicularity to the block surface.

c. When FBH size is plotted versus respective ultrasonic echo amplitude for a given equipment setup, a straight line ±2 dB SHOULD pass through the plotted points.

5.6.2.3 Angle Beam Reference Standards. There are two types of angle beam calibration blocks included in AS 455: the miniature angle beam block and the International Institute of Welding Type 2 IIW block (Figure 5-77). Either of these blocks MAY be used to perform the following tests for angle beam transducers:

a. Check the refracted angle of the sound beam.

b. Check the point-of-incidence of the refracted sound beam.

c. Determine skew angle.

NOTE

Angle beam blocks made of aluminum and steel are standard; other materials MAY be specifically ordered.

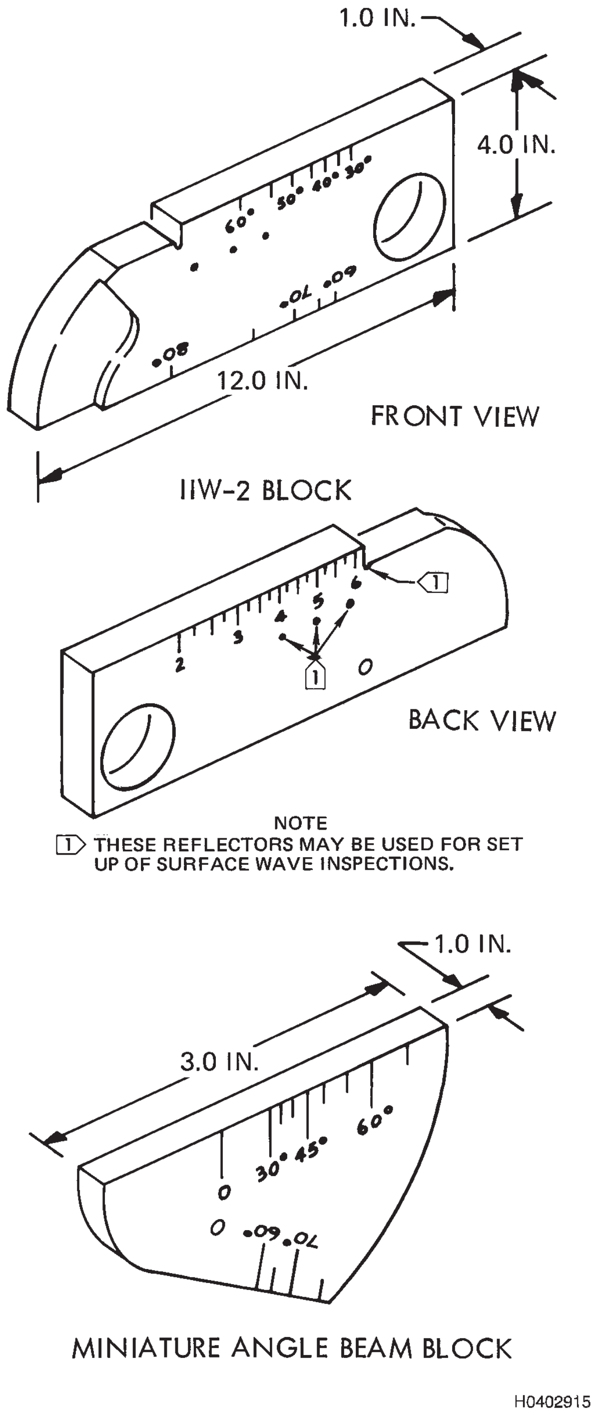


Figure 5-77. Angle Beam Block

5.6.2.4 Surface Wave Reference Standards. A variety of reflectors can be used to set up surface wave inspections. Electrical discharge machined notches, saw cuts, chiseled notches, and drilled holes can be used. Suggested surface wave standards are the side-drilled holes and the notch in the IIW block, when the transducer is placed on the large front, or back surface of the block. The reflected signal from one of the holes, or the notch, can be compared with the reflected signals from discontinuities in test parts. Signals SHOULD be compared at equivalent travel distances (distance from transducer to reference standard reflector, equal to distance from transducer to test part discontinuity).

5.6.3 System (Equipment) Checks. The most important system check is the calibration or standardization of each inspection setup through use of the applicable calibration or reference standards. An ultrasonic system consists of the instrument, search unit (transducer) and the coaxial cable. It is essential this calibration or standardization be accomplished before each and every inspection. Additionally, there are general calibration procedures that can be used to ensure the system is within the parameters required to perform ultrasonic inspections. The specific procedures, located in TO 33B-1-2 WP 105 00, SHOULD be performed, and documented, at the time intervals prescribed in applicable specifications or procedures, and whenever an operator suspects there is a problem with the equipment.

5.6.3.1 System Linearity.

5.6.3.1.1 Vertical Linearity.

5.6.3.1.1.1 Limits.

5.6.3.1.1.1.1 The upper linearity limit is the level of vertical deflection defining the upper limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of known size.

5.6.3.1.1.1.2 The lower linearity limit is the level of vertical deflection defining the lower limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of known size.

5.6.3.1.2 Horizontal Linearity.

5.6.3.1.2.1 Definitions.

5.6.3.1.2.1.1 The horizontal limit is the maximum readable length of horizontal deflection determined either by an electrical or physical limit in the A-scan presentation of an ultrasonic testing instrument. Horizontal limit is expressed as the maximum observed deflection in inches from the left side, or the start, of the horizontal line representing the time base.

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

5.6.3.2 System Sensitivity. Sensitivity is a measure of the ability of the inspection system (e.g., instrument and transducer) to detect discontinuities producing relatively low-amplitude signals because of the size, geometry, or location of the discontinuities. Noise can limit the ability to detect discontinuities by masking their indications. Generally, sensitivity, resolution and signal-to-noise ratio are interdependent and SHOULD be evaluated under similar test conditions.

5.6.3.3 System Resolution. Resolution is the minimum spacing between discontinuities for which separate and distinct ultrasonic echo signals can be obtained. Spatial resolution refers to the lateral separation of discontinuities. Depth resolution, as the name implies, refers to depth separation between internal discontinuities or a discontinuity and a boundary surface. The following procedures are concerned only with entry and back surface resolutions, which are defined as the inspectable distances nearest to the respective surfaces of the test material. Resolution SHALL be checked when specified and SHALL meet the minimum requirements as given in (Table 5-5). This evaluation requires a reference standard with reference discontinuities at the respective distances from the appropriate surfaces of the standard.

NOTE

The 1 MHz and 15 MHz requirements are applicable only when these frequencies are used; they are not general requirements for all instruments.

Table 5-5. Limits of Boundary Surface Resolution

Frequency (MHz)	1	2.25	5	10	15
Entry Surface Resolution in Aluminum (inch)	0.5	0.375	0.25	0.125	0.125
Back Surface Resolution in Aluminum (inch)	0.5	0.3	0.2	0.1	0.1

5.6.4 Transducer Verifications.

NOTE

- Verification checks as written in this Technical Order may not be reproducible on some special purpose transducers mainly due to construction features of the transducer. Manufacturer's guidelines SHALL be used for special purpose transducers that cannot be inspected with this technical order or TO 33B-1-2.

- ARMY ONLY: Special Purpose transducers that cannot be verified utilizing the process control checks outlined in this Technical Manual SHALL be evaluated by monitoring changes in signal-to-noise ratio during the inspection calibration process. For example, the UH-60 Black Hawk Spindle Lug Kit SHALL be monitored for signal-to-noise degradation by completing the inspection standardization IAW the latest procedure. Once the standardization has been completed, the inspector SHALL document the highest peak noise across the screen range WHILE the reference standard EDM notch is optimized. Signal-to-noise SHALL NOT exceed 3-1 (i.e. 80% FSH from EDM notch - Noise SHALL be less than 25% FSH).

5.6.4.1 Angle Beam Transducer Parameters. The angle of new and used ultrasonic transducers SHALL be maintained within 2-degrees of what is required to perform an ultrasonic inspection. Transducers that do not fall within this parameter SHALL NOT be used to perform ultrasonic inspections. If possible, transducers out of tolerance SHALL be reworked within parameters to extend their usefulness. The rework procedure consists of wet sanding the wear plate/wedge very slowly using 600-grit or finer sandpaper, or equivalent emery cloth. Extreme care SHALL be taken during sanding not to raise the temperature of the wear plate/wedge. Temperature increases will affect the acoustic impedance of the wear plate/wedge and therefore, the overall transducer sensitivity.

5.6.4.2 Angle Beam Checks. Calibration prior to angle beam inspection is typically accomplished with use of Type 2 IIW standard calibration block. Prior to accomplishing any angle beam calibrations, the beam point of incidence, refracted angle, and skew angle.

5.6.4.2.1 Point-of-Incidence.

NOTE

Due to a problem with the Type 2 IIW aluminum reference blocks, it SHALL NOT be used for determining the point-of-incidence on all shear wave transducers having a refracted angle greater than 45° (e.g., 60°, 70°, etc.). A steel Type 2 IIW block or the steel miniature block SHALL be used for testing Point-of-Incidence (POI) on all shear wave transducers over 45° intended for aluminum inspections. All other process control tests will be performed using the correct material reference block for the transducer used.

5.6.4.2.1.1 Angle Beam Point-of-Incidence (Type 2 IIW Block). The point-of-incidence is defined as the center point of the sound beam exiting the transducer wedge. It is usually indicated by a mark on the side of the wedge at the point where an imaginary line through the exit point of the beam intersects the side of the wedge. The procedure for determining the angle beam point-of-incidence is published in TO 33B-1-2, WP 105 00.

5.6.4.2.2 Angle Beam Misalignment (Skew Angle). Skew angle is a measure of the misalignment angle between the ultrasonic beam and the search units' axis of symmetry. The procedure for determining the angle beam skew angle is published in TO 33B-1-2, WP 105 00.

5.6.4.2.3 Transducer Angle Determination. Angle beam transducers and wedges are labeled with their refracted angle in a given material. For example, a transducer labeled "45° AL", will produce a 45° refracted wave in aluminum. The angle determination is used to verify the refracted angle produced from the transducer/wedge is accurate. The procedures for determining the angle of a transducer is published in TO 33B-1-2 WP 105 00.

SECTION VII ULTRASONIC INSPECTION EQUATIONS

5.7 INTRODUCTION.

5.7.1 General. Understanding where your sound beam is located is very important in order to distinguish relevant discontinuities from non-relevant discontinuities.

5.7.2 Snell's Law. As covered in paragraph 5.2.4.1, when an incident longitudinal beam is normal to the test part surface ($\theta_1 = 0°$), the longitudinal sound beam is transmitted straight into the test part and no refraction occurs. When the incident angle is other than normal, refraction, reflection, and mode conversion occur. Refraction is a change in propagation direction. Mode conversion is a change in the nature of the wave motion. A portion of the longitudinal incident beam is refracted into one or more wave modes traveling at various angles in the test piece (Figure 5-6). Wave behavior at an interface is defined by Snell's Law. The Snell's Law formula follows:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\nu_1}{\nu_2}$$

Where:
θ_1 = angle of incidence
θ_2 = angle of refracted beam
V_1 = velocity of incident sound beam
V_2 = velocity of refracted sound beam

5.7.3 Determining the Angle of Incidence in Plastic to Generate 45-Degree Shear Wave in Aluminum. As covered in paragraph 5.2.4.4, Snell's law is the tool for determining wedge angles for contact testing (paragraph 5.4.2.1.1.1), or the angle-of-incidence in water for immersion testing (paragraph 5.4.2.1.1.2). The following example shows how Snell's law is used to obtaining the required refracted beam and determine the angle-of-incidence in plastic to generate 45-degree shear waves in aluminum:

If:
θ_2 = 45°
ν_1 = velocity of a longitudinal wave in plastic wedge = $1.05X10^5$ in/sec (see Table 5-6)
ν_2 = velocity of shear waves in aluminum = $1.22x10^5$ in/sec (see Table 5-6)

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\nu_1}{\nu_2} \text{ then, } \frac{\sin\theta_1}{.707} = \frac{1.05x10^5}{1.22x10^5} \text{ then, } \sin\theta_1 = \frac{(.707)(1.05x10^5)}{(1.22x10^5)} \text{ then } \sin\theta_1 = 0.608$$

Therefore, θ_1 = 37.5°

5.7.4 Wavelength. The term "wavelength" is the distance a wave travels while going through one cycle. As a rule of thumb, the smallest detectable flaw is equal to half the wavelength. Wavelength is defined by the formula:

λ (lambda) = v/f

Where:
λ = wavelength (normally inches or centimeters)
v = velocity (inches or centimeters per second)
f = frequency (hertz)

Example: Calculate the wavelength for a 2.25 MHz longitudinal transducer in aluminum if the velocity is 2.46 X 105 in/sec.

λ = v/f λ = (2.46)2.25 λ = 1.09

To calculate the smallest detectable flaw, divide by 2:
1.09/2 = 0.545

5.7.5 Near Field. The near field (paragraph 5.2.6.2) extends from the face of the transducer and is an area characterized by wide variations in sound beam intensity. These intensity variations are due to the interference effects of spherical wave fronts (side lobes) emanating from the periphery of the transducer crystal. The region where this side lobe interference occurs is called the near field (Fresnel Zone) (Figure 5-8). Due to inherent amplitude variations, inspection within the near field is not typically recommended. The length of the near field is calculated with the following equation:

$$N = \frac{D^2}{4\lambda} = \frac{D^2 f}{4v}$$

H0402934

Where:
N = near field length (inches)
D = diameter of transducer element in a round transducer or maximum diagonal of transducer element in a rectangular or square transducer (inches)
λ = wavelength of sound in the test material (inches)
f = frequency (Hz)
v = velocity (in/sec)

Example:
If the diameter of a 5 MHz transducer is.5 inches and aluminum 1100-0 is under inspection:

$$N = \frac{D^2}{4\lambda} \text{ then, } N = \frac{(.5)^2}{(4)(.050)} \text{ then, } N = \frac{.25}{.200} \text{ then } N = 1.25 \textit{ inches}$$

5.7.5.1 The smaller the transducer element diameter or the lower the frequency, the shorter the near field will be. Due to inherent amplitude variations, inspection within the near field is not recommended without careful calibration on reference flaws within the near field.

5.7.6 Beam Spread. As covered in paragraph 5.2.6.5, the sound beam in the near field, essentially propagates straight out from the face of the transducer. In the far field, the sound beam spreads outward and decreases in intensity with increasing distance from the transducer face as shown in Figure 5-9. Beam spread is an important consideration, because in certain inspection applications the spreading sound beam could result in erroneous or confusing A-scan presentations. The half-angle of the beam spread is calculated as follows:

$$\sin\theta = \frac{1.22\,\lambda}{D} \quad or \quad \sin\theta = \frac{1.22\,\nu}{fD}$$

Where:
θ = half-angle of spread
D = transducer diameter (inches)
λ = wavelength (inches)
f = frequency (Hz)
v = velocity (in/sec)

Example: Given 2014-T4 aluminum being tested with a 1/4-inch diameter unit at 5 MHz, what is the half angle of the beam spread?

D = 1/4 inch (0.25 inch)
λ = 0.049 inch

$$\sin\theta = \frac{1.22\,\lambda}{D} \text{ then, } \sin\theta \frac{(1.22)(0.049)}{.25} \text{ then, } \sin\theta = 0.2391 \text{ then } \theta = 14^{o}$$

Remember this is the half angle value; to get the full angle of the beam spread it is necessary to double the achieved value of the angle θ.

As denoted by the beam spread formula at a given frequency, the smaller the transducer element, the greater the beam spread. Also, for a given diameter, a lower frequency results in more beam spread.

5.7.7 Calculating Acoustic Impedance. As covered in paragraph 5.5.4.3, the reflections from an air interface, such as a crack or void are large due to the acoustic impedance ratio. If a discontinuity had acoustic impedance close to the acoustic impedance of the test material, the acoustic impedance ratio would be small and very little reflection would occur. When an ultrasonic beam strikes a boundary between two different materials, part of the energy is transmitted to the second medium and a portion is reflected. The percentage of sound energy transmitted and reflected is related to the ratio of the acoustic impedances of the two materials. Acoustic impedance can be calculated as follows:

$$Z = \rho v$$

Where:
Z = acoustic impedance of a material (lb/in^2-sec)
ρ (rho) = material density (lb/in^3)
v = velocity of sound in the material (in/sec)

If the material density of aluminum 2014 is .1012 and velocity is 2.46 x 10^5

$Z = \rho\nu$ then, Z = (.1012)(246000) then, Z = 24895 lb/in ^{2} – sec

5.7.7.1 Determining Reflected Energy at the Interface. Acoustic impedance can be used to calculate the theoretical reflected and transmitted energy for an interface. The following formula is used to determine the amount of reflected energy that occurs at an interface.

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \times 100$$

H0402935

Where:
R = percentage of energy reflected at the interface.
Z_2 = acoustic impedance of the discontinuity (lb/in ^{2}-sec)
Z_1 = acoustic impedance of the test material (lb/in ^{2}-sec)

Example: A tungsten inclusion is found in a piece of titanium. How much energy will be reflected at the interface if 100-percent of the sound energy strikes the tungsten?

Known from:
Acoustic impedance of tungsten (Z_2) = 14.20 (10^4 (lb/in ^{2}-sec))
Acoustic impedance of titanium (Z_1) = 3.94 (10^4 (lb/in ^{2}-sec))

Solution:

$$R = \left(\frac{14.20 - 3.94}{14.20 + 3.94}\right)^2 \times 100 = \left(\frac{10.26}{18.14}\right)^2 \times 100 = (0.5656)^2 \times 100 = 0.32 \times 100 = 32\%$$

H0402936

Therefore, 32-percent of the energy will be reflected at the interface by the tungsten inclusion. A crack would reflect virtually 100-percent of the energy because it is filled with air.

5.7.8 Thickness Measurement Correlation Factor. As we covered in paragraph 5.4.11.3, prior to performing thickness measurement, consult the instruments operator's manual to see if one or two reference standards are required. If two are required, it is best to have one 50-90-percent of the nominal thickness to be measured, and one 110-150-percent of the nominal thickness to be measured. Only one reference standard is required when using a basic pulsed instrument for thickness measurement. Direct, accurate readings of thickness can be obtained only when the acoustic velocity in the reference standard is equal to the acoustic velocity in the test part. For this reason, the material and heat treat condition of the reference standard SHOULD be identical to the test part. If reference standards, of a different material, or heat treat condition is used; the resultant thickness readings SHALL be corrected by a correlation factor. The correlation factor MAY be established in two ways:

a. Use the ratio when the velocities of the test part and reference standard are known.

$$\frac{V_2}{V_1}$$

Where:

v_2 = acoustic velocity in the test part material

v_1 = acoustic velocity in the reference standard material

Example: Assume the calibration blocks are made of 2014-T4 aluminum and the test part material is 410 stainless steel.

v_2 = longitudinal wave velocity in 410 stainless steel = 2.91 x 10^5 inches/sec.

v_1 = longitudinal wave velocity in 2014-T4 aluminum = 2.46 x 10^5 inches/sec.

$$\frac{V_2}{V_1} = \frac{2.91\,x10^5}{2.46\,x10^5} = 1.18 = \text{The Correlation Factor}$$

All readings on the test part are now multiplied by 1.18 to obtain the actual thickness. If a test part reading is 0.110-inch, correct this by multiplying by the correlation factor:

0.110-inch x 1.18 = 0.130-inch = the actual test part thickness

b. Use this ratio when one area of the test part is accessible for direct measurement.

$$\frac{d_2}{d_1}$$

H0402939

Where:

d_2 = the thickness of an area of the test part as measured by mechanical or optical means (inch)

d_1 = the thickness of the same area as indicated by the ultrasonic instrument calibrated on material similar to the test part (inch)

Example: Assume an area of a test part is measured with a micrometer and is 0.167-inch thick (d_2 = 0.167-inch). This same area is measured with ultrasonic instrument and gives a reading of 0.133-inch (d_1 = 0.133-inch).

c. $$\frac{d_2 = 0.167}{d_1 = 0.133} = 1.25 = \text{the correlation factor}$$

H0402940

d. All ultrasonic readings on the test part are now multiplied by 1.25 to obtain the actual thickness. If another area of the test part gives an ultrasonic reading of 0.200-inch, correct this by multiplying by the correlation factor:

0.200-inch x 1.25 = 0.250-inch = the actual test part thickness.

SECTION VIII ULTRASONIC INSPECTION SAFETY

5.8 INTRODUCTION.

5.8.1 Safety Requirements. Safety requirements SHALL be reviewed by the laboratory supervisor on a continuing basis to ensure compliance with provisions contained in AFI 91-203, as well as, provisions of this technical order and applicable weapons systems technical orders. Recommendations of the Base Bioenvironmental Engineer and the manufacturer regarding necessary personnel protective equipment SHALL be followed.

NOTE

Air Force Instruction 91-203 or appropriate service directive shall be consulted for additional safety requirements.

5.8.2 General Precautions. Precautions to be exercised when performing ultrasonic inspection include consideration of exposure to electrical current. The following minimum safety requirements SHALL be observed when performing ultrasonic inspections.

5.8.3 Ultrasonic Inspection. Ultrasonic equipment can safely be used in and around aircraft provided the following electrical safety guidelines are followed.

5.8.3.1 Care SHALL be exercised when performing maintenance on or around the cathode-ray tube (CRT) of equipment.

5.8.3.1.1 Ensure the CRT is electrically discharged according to applicable manufacturer's technical manuals prior to performing any maintenance on the equipment.

5.8.3.1.2 Use care not to break the CRT, since a violent implosion can result.

5.8.3.2 Hazards exist when ultrasonic equipment is not properly used in some hazardous environments. Consult the local safety authority for guidance prior to performing ultrasonic inspections in a hazardous area.

Table 5-6. Ultrasonic Properties of Materials

Material	Velocity (10^5 inches/sec)			Wave Length (inches)												Acoustic impedance (10^4 lb/in^2-sec)
	Longitudinal Waves	Shear Waves	Surface Waves	Longitudinal Waves (MHz)				Shear Waves (MHz)				Surface Waves (MHz)				
				1	2.25	5	10	1	2.25	5	10	1	2.25	5	10	
METALS:																
Aluminum 1100 - 0	2.50	1.22	1.14	0.250	0.111	0.050	0.025	0.122	0.054	0.024	0.012	0.114	0.051	0.023	0.011	2.45
Aluminum 2014 - T4	2.46	1.22	1.10	0.246	0.109	0.049	0.025	0.122	0.054	0.024	0.012	0.110	0.049	0.022	0.011	2.49
Beryllium	5.02	3.43	3.10	0.502	0.224	0.101	0.050	0.343	0.152	0.069	0.034	0.310	0.138	0.062	0.031	3.32
Brass, Naval	1.75	0.83	0.77	0.175	0.078	0.035	0.017	0.083	0.037	0.017	0.008	0.077	0.034	0.015	0.008	5.13
Bronze, Phosphor, 5%	1.39	0.88	0.79	0.139	0.062	0.028	0.014	0.088	0.039	0.018	0.009	0.079	0.035	0.016	0.008	4.44
Copper	1.84	0.89	0.76	0.184	0.081	0.037	0.018	0.089	0.040	0.018	0.009	0.076	0.034	0.015	0.008	5.96
Lead, Pure	0.85	0.28	0.25	0.085	0.038	0.017	0.009	0.028	0.012	0.006	0.003	0.025	0.011	0.005	0.003	3.50
Lead, Antimony, 6%	0.85	0.32	0.29	0.085	0.038	0.017	0.009	0.032	0.014	0.006	0.003	0.029	0.013	0.006	0.003	3.36
Molybdenum	2.48	1.32	1.22	0.248	0.110	0.050	0.025	0.132	0.059	0.026	0.013	0.122	0.054	0.024	0.012	9.04
Nickel	2.22	1.17	1.04	0.222	0.099	0.044	0.022	0.177	0.052	0.023	0.012	0.104	0.046	0.021	0.010	7.05
Inconel, Wrought	3.08	1.19	1.10	0.308	0.136	0.06 2	0.031	0.119	0.053	0.024	0.012	0.110	0.049	0.022	0.011	9.18
Monel, Wrought	2.38	0.97	0.77	0.23 8	0.10 6	0.04 8	0.024	0.107	0.048	0.021	0.011	0.077	0.034	0.015	0.008	7.56
Silver - 18Ni	1.82	0.91	0.66	0.182	0.080	0.036	0.018	0.091	0.040	0.018	0.009	0.066	0.029	0.013	0.007	5.74
Iron	2.32	1.27	1.10	0.232	0.103	0.046	0.023	0.127	0.056	0.025	0.013	0.110	0.049	0.022	0.011	6.45
Iron, Cast	1.89	0.95		0.189	0.084	0.039	0.019	0.095	0.042	0.019	0.010					5.30
Steel, 302	2.24	1.23	1.23	0.223	0.099	0.045	0.022	0.123	0.055	0.025	0.012	0.123	0.055	0.025	0.012	6.35
Steel, 347	2.26	1.22		0.226	0.100	0.045	0.023	0.122	0.054	0.024	0.012					6.35
Steel, 410	2.91	1.18	0.85	0.291	0.129	0.058	0.029	0.118	0.052	0.024	0.012	0.085	0.038	0.017	0.00 9	8.05
Steel 1020	2.32	1.28		0.232	0.103	0.046	0.023	0.128	0.057	0.026	0.013					6.45
Steel 1095	2.32	1.26		0.232	0.103	0.046	0.023	0.126	0.056	0.025	0.013					6.53

Table 5-6. Ultrasonic Properties of Materials - Continued

Material	Velocity (10^5 inches/sec)			Wave Length (inches)												Acoustic impedance (10^4 lb/in^2-sec)
	Longitudinal Waves	Shear Waves	Surface Waves	Longitudinal Waves (MHz)				Shear Waves (MHz)				Surface Waves (MHz)				
				1	2.25	5	10	1	2.25	5	10	1	2.25	5	10	
Steel, 4150, Rc 14	2.31	1.10		0.231	0.103	0.046	0.023	0.110	0.049	0.022	0.011					6.52
Steel, 4150, Rc 18	2.31	1.25		0.231	0.103	0.046	0.023	0.125	0.056	0.025	0.012					6.53
Steel, 4150, Rc 43	2.31	1.26		0.231	0.103	0.046	0.023	0.126	0.056	0.025	0.013					6.51
Steel, 4150, Rc 64	2.30	1.09		0.230	0.102	0.046	0.023	0.109	0.048	0.022	0.011					6.46
Steel, 4340	2.30	1.26		0.230	0.102	0.046	0.023	0.126	0.056	0.025	0.013					7.24
Titanium, 150 A	2.40	1.23	1.10	0.240	0.107	0.048	0.024	0.123	0.055	0.025	0.012	0.110	0.049	0.022	0.011	3.94
Tungsten	2.04	1.13	1.04	0.204	0.091	0.041	0.020	0.113	0.050	0.023	0.011	0.104	0.046	0.021	0.010	14.20
NON-METALS:																
Air	0.13	1.13		0.013	0.006	0.003	0.001									0.00047
Water	0.59			0.059	0.026	0.012	0.006									0.212
Motor Oil, SAE20	0.68			0.068	0.030	0.014	0.007									0.214
Transformer Oil	0.54			0.054	0.024	0.011	0.005									0.181
Bakelite	1.02			0.102	0.045	0.020	0.010									0.515
Lucite	1.06	0.50		0.106	0.047	0.021	0.011	0.050	0.022	0.010	0.005				0.005	0.448
Plastic, Acrylic Resin	1.05	0.44		0.105	0.047	0.021	0.011	0.044	0.020	0.009	0.004					0.455
Plexiglass	1.09			0.109	0.048	0.022	0.011									0.494
Teflon	0.57			0.057	0.025	0.011	0.006									0.426
Quartz, Natural	2.26			0.226	0.100	0.045	0.023									2.16
Fused Quartz	2.33	1.48	1.33	0.233	0.104	0.047	0.023	0.148	0.066	0.030	0.015	0.133	0.059	0.027	0.013	1.85
Pyrex	2.20	1.35	1.23	0.220	0.098	0.044	0.022	0.135	0.060	0.027	0.014	0.123	0.055	0.025	0.012	1.77

Table 5-6. Ultrasonic Properties of Materials - Continued

Material	Velocity (10^5 inches/sec)			Wave Length (inches)												Acoustic impedance (10^4 lb/in^2-sec)
				Longitudinal Waves (MHz)				Shear Waves (MHz)				Surface Waves (MHz)				
	Longitudinal Waves	Shear Waves	Surface Waves	1	2.25	5	10	1	2.25	5	10	1	2.25	5	10	
Plate Glass	2.28	1.35	1.24	0.228	0.101	0.046	0.023	0.135	0.060	0.027	0.014	0.124	0.055	0.025	0.012	2.06

Table 5-7. Measurement Error Introduced by Surface Roughness of Reference Standard or Test Part

Surface Finish (microinches)	Measurement Error (inch)
0 - 63	0.0005
63 - 125	0.002
125 - 250	0.005
250 - 500	0.010
500 - 20000	0.020

Table 5-8. Incident Longitudinal Wave Angle in Plastic (degrees)

Refracted Shear Wave Angle in Test Materials (Degrees)	Steel	Stainless Steel 302	Stainless Steel 410	Ti 150A	A1 1100-0	AL 2014-T4	Inconel Wrought	Magnesium AM 35
20	16.4	17	17.8	17	17.1	17.1	17.6	17.1
21	17.2	17.9	18.7	17.9	18	18	18.5	18
22	18	18.7	19.5	18.7	18.8	18.8	19.3	18.8
23	18.8	19.5	20.4	19.5	19.7	19.7	20.2	19.7
24	19.6	20.4	21.3	20.4	20.5	20.5	21.1	20.5
25	20.4	21.2	22.2	21.2	21.3	21.3	21.9	21.3
26	21.2	22	23	22	22.2	22.2	22.8	22.2
27	22	22.9	23.9	22.9	23	23	23.7	23
28	22.8	23.7	24.8	23.7	23.9	23.9	24.5	23.9
29	23.6	24.5	25.7	24.5	24.7	24.7	25.4	24.7
30	24.4	25.3	26.5	25.3	25.5	25.5	26.2	25.5
31	25.2	26.2	27.4	26.2	26.3	26.3	27.1	26.3
32	26	27	28.2	27	27.2	27.2	27.9	27.2
33	26.8	27.8	29.1	27.8	28	28	28.8	28
34	27.5	28.6	30	28.5	28.8	28.8	29.6	28.8
35	28.3	29.4	30.8	29.4	29.6	29.6	30.5	29.6
36	29.1	30.2	31.7	30.2	30.4	30.4	31.3	30.4
37	29.8	31	32.5	31	31.2	31.2	32.1	31.2
38	30.6	31.8	33.4	31.8	32	32	33	32
39	21.3	32.5	34.2	32.6	32.8	32.8	33.8	32.8
40	32.1	33.4	35	33.4	33.6	33.6	34.6	33.6
41	32.8	34.2	35.9	34.2	34.4	34.4	35.5	34.4
42	33.6	34.9	36.7	34.9	35.2	35.2	36.3	35.2
43	34.3	35.7	37.5	35.7	36	36	37.1	36
44	35	36.5	38.3	36.5	36.7	36.7	37.9	36.7
45	35.8	37.2	39.2	37.2	37.5	37.5	38.7	37.5
46	36.5	38	40	38	38.3	38.3	39.5	38.3
47	37.2	38.7	40.8	38.7	39	39	40.3	39

Table 5-8. Incident Longitudinal Wave Angle in Plastic (degrees) - Continued

Refracted Shear Wave Angle in Test Materials (Degrees)	Steel	Stainless Steel 302	Stainless Steel 410	Ti 150A	A1 1100-0	AL 2014-T4	Inconel Wrought	Magnesium AM 35
48	37.9	39.5	41.4	39.5	39.8	39.8	41.1	39.8
49	38.5	40.2	42.4	40.2	40.5	40.5	41.9	40.5
50	39.3	41	43.2	41	41.3	41.3	42.6	41.3
51	40	41.7	43.9	41.7	42	42	43.4	42
52	40.6	42.4	44.7	42.4	42.7	42.7	44.2	42.7
53	41.3	43.1	45.5	43.1	43.5	43.5	44.9	43.5
54	42	43.8	46.3	43.8	44.2	44.2	45.7	44.2
55	42.6	44.5	47	44.5	44.9	44.9	46.4	44.9
56	43.3	45.2	47.8	45.2	45.6	45.6	47.1	45.6
57	43.9	45.9	48.5	45.9	46.2	46.2	47.9	46.2
58	44.5	46.5	49.2	46.5	46.9	46.9	48.5	46.9
59	45.1	47.2	49.9	47.2	47.6	47.6	49.3	47.5
60	45.7	47.4	50.4	47.7	48.2	48.2	49.8	48.2
61	46.3	48.5	51.4	48.5	48.9	48.9	50.6	48.9