

ASNT Level-III Study Guide Ultrasonic Method

by
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The American Society for Nondestructive Testing, Inc.

The Ultrasonic Level III Study Guide, prepared by Dr. Matthew J. Golis, is partially based on earlier efforts by Robert Baker and Joseph Bush.

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Preface

This study guide has been developed to assist persons preparing to take the Ultrasonic Level III examination offered through ASNT. It is intended to feature the major concepts considered central to the traditional uses of Ultrasonics NDT as it is practiced throughout **the** USA, and to present abstracts of several of the typical technical specialties, codes, and standards from which "applications" questions are sometimes derived. It is not intended to be a comprehensive coverage of all possible technical issues that may appear on the Level III test, but rather it is intended to reflect the breadth of the possible technology topics which comprise potential questions material. It is vital that the supplemental references be carefully reviewed to amplify on the statements in the Guide in order to place each technical topic into its proper context.

The problems at the end of each section **are** intended to be used as feedback regarding the user's understanding of the concepts discussed in the sections. They require both a general understanding of many of the topics as well as an ability to solve complex interpretation and analysis issues. Mixed systems of units are used (both English and metric) because both are found in contemporary codes and specifications. They sometimes call for interpretations of graphs, plots, and related figures, which are an integral part of the language of the engineering sciences and technologies.

Suggestions for improvement to the Guide, its questions, or the related codes and specifications should be sent to Educational Materials Coordinator, ASNT, 1711 Arlingate Lane. PO Box 285 18, Columbus, OH 43228-0518. The author acknowledges the support given to this project by the technical reviewers, publications staff at ASNT, and particularly the Technical Services Department, who recognized **the** need for this document and made the necessary arrangements for getting it completed.

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Chapter 1

Physical Principles

Chapter I

Physical Principles

Sound is the propagation of mechanical energy (vibrations) through solids, liquids and gases. The ease with which the sound travels, however, is dependent upon the detailed nature of the material and the pitch (frequency) of the sound. At ultrasonic frequencies (above 20,000 Hertz [Hz]), sound propagates well through most elastic or near-elastic solids and liquids, particularly those with low viscosities. At frequencies above 100 kilohertz (kHz), sound energy can be formed into beams, similar to that of light, and thus can be scanned throughout a material, not unlike that of a flashlight used in a darkened room. Such sound beams follow many of the physical rules of optics and thus can be reflected, refracted, diffracted and absorbed (when nonelastic materials are involved). At extremely high frequencies (above 100 megahertz [MHz]), the sound waves are severely attenuated and

propagation is limited to short travel distances. The common wave modes and their characteristics are summarized in Table 1.1.

Wave Characteristics

The propagation of ultrasonic waves depends on the mechanical characteristics of density and elasticity, the degree to which the material supporting the waves is homogeneous and isotropic, and the diffraction phenomena found with continuous (or quasi-continuous) waves.

Continuous waves are described by their wavelength, i.e., the distance the wave advances in each repeated cycle. This wavelength is proportional to the velocity at which the wave is

Table 1.1. Common Wave Mode Characteristics

Mode	Notable Characteristics	Velocity	Alternate Names
Longitudinal	Bulk wave in all media In-line motion	VL	Pressure Wave Dilatational (Straight Beam)
Transverse	Bulk wave in solids Polarized, <i>e.g.</i> S_V , S_H Transverse motion	$V_T \sim 1/2 V_L$	Shear Torsional (Angle Beam)
Surface (Guided)	Boundary wave in solids Polarized vertically Elliptical motion Polarized horizontally	$V_R \sim 0.9 V$	Rayleigh Wave Love Wave
Plate (Guided)	Twin-boundary wave - solids Symmetrical Hourglass motion Asymmetrical Flexing motion	$F(f,T,m)$	Lamb Wave
(...) ~ $F(f, T, m)$	Common colloquial terms Signifies approximate relationship for common materials Depends on Frequency, Thickness, and Material		

advancing and is inversely proportional to its frequency of oscillation. Wavelength may be thought of as the distance from one point to the next identical point along the repetitive waveform. Wavelength is described mathematically by Equation 1-1.

$$\text{Wavelength} = \text{Velocity/Frequency} \quad (\text{Eq. 1-1})$$

The velocity at which bulk waves travel is determined by the material's elastic moduli and density. The expressions for longitudinal and transverse waves are given in Equations 1-2 and 1-3, respectively.

$$V_L = \sqrt{\frac{E}{\rho} \frac{(1-\mu)}{(1+\mu)(1-2\mu)}} \quad (\text{Eq. 1-2})$$

$$V_T = \sqrt{\frac{E}{\rho} \frac{1}{2(1+\mu)}} \quad (\text{Eq. 1-3})$$

where

V_L is the longitudinal bulk wave velocity,
 V_T is the transverse (shear) wave velocity,
 G is the shear modulus,
 E is Young's modulus of elasticity
 μ is the Poisson ratio, and
 ρ is the material density.

Typical values of bulk wave velocities in common materials are given in Table 1.2. A more complete list is given in Appendix A. From Table 1.2 it is seen that, in steel, a longitudinal wave travels at 5.9 km/sec, while a shear

wave travels at 3.2 km/sec. In aluminum, the longitudinal wave velocity is 6.3 km/sec while the shear velocity is 3.1 km/sec. The wavelengths of sound for each of these materials are calculated using Equation 1-1 for each applicable test frequency used. For example, a 5 MHz L-wave in water has a wavelength equal to $1483/5(10)^6$ m or 0.298 mm.

When sound waves are confined within boundaries, such as along a free surface or between the surfaces of sheet materials, the waves take on a very different behavior, being controlled by the confining boundary conditions. These types of waves are called guided waves, i.e., they are guided along the respective surfaces, and exhibit velocities that are dependent upon elastic moduli, density, thickness, surface conditions, and relative wavelength interactions with the surfaces. For Rayleigh waves, the useful depth of penetration is restricted to about one wavelength below the surface. The wave motion is that of a retrograde ellipse. Wave modes such as those found with Lamb waves have a velocity of propagation dependent upon the operating frequency, sample thickness and elastic moduli. They are dispersive (velocity changes with frequency) in that pulses transmitted in these modes tend to become stretched or dispersed as they propagate in these modes and/or materials which exhibit frequency-dependent velocities.

Reflection

Ultrasonic waves, when they encounter a discrete change in materials, as at the boundary of two dissimilar materials, are usually partially reflected. If the incident waves are perpendicular to the material interface, the reflected waves are redirected back toward the source from which they came. The degree to which the sound energy is reflected is dependent upon the difference in acoustic properties, i.e., acoustic impedances, between the adjacent materials.

Acoustic impedance (Equation 1-4) is the product of a wave's velocity of propagation and the density of the material through which the wave is passing.

$$Z = \rho * V \quad (\text{Eq. 1-4})$$

Table 1.2. Acoustic Velocities and Impedance of Common Materials

Material	VL (m/sec)	VT (m/sec)	Z
Steel	5900	3230	45.0
Aluminum	6320	3130	17.0
Plexiglas™	2730	1430	3.2
Water	1483	---	1.5
Quartz	5800	2200	15.2

where

Z is the acoustic impedance,

p is the density, and

V is the applicable wave velocity.

Table 1.2 lists the acoustic impedances of several common materials.

The degree to which a perpendicular wave is reflected from an acoustic interface is given by the energy reflection coefficient. The ratio of the reflected acoustic energy to that which is incident upon the interface is given by Equation 1-5.

$$R = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} \quad (\text{Eq. 1-5})$$

where

R is the Coefficient of Energy Reflection for normal incidence

Z is the respective material acoustic impedances with

Z_1 = incident wave material,

Z_2 = transmitted wave material,

and

T is the Coefficient of Energy Transmission.

Note: $T + R = 1$

In the ease of water-to-steel, approximately 88 percent of the incident longitudinal wave energy is reflected back into the water, leaving 12 percent to be transmitted into the steel¹. These percentages are arrived at using Equation 1-5 with $Z = 45$ and $Z = 1.5$. Thus,

$$R = (45 - 1.5)^2 / (45 + 1.5)^2 = (43.5 / 46.5)^2 = 0.875, \text{ or } 88 \text{ percent and } T = 1 - R = 1 - 0.88 = 0.12, \text{ or } 12 \text{ percent.}$$

Refraction

When a sound wave encounters an interface at an angle other than perpendicular (oblique incidence), reflections occur at angles equal to the incident angle (as measured from the normal or perpendicular axis). If the sound energy is partially transmitted beyond the interface, the transmitted wave may be (1) refracted (bent), depending on the relative acoustic velocities of the respective media, and/or (2) partially converted to

a mode of propagation different from that of the incident wave. Figure 1.1a shows normal reflection and partial transmission, while Figure 1.1b shows oblique reflection and the partition of waves into reflected and transmitted wave modes.

Referring to Figure 1.1 b, Snell's Law may be stated as:

$$\sin \beta = \left(\frac{V_2}{V_1} \right) \sin \alpha \quad (\text{Eq. 1-6})$$

For example, at a *water plexiglas*TM inter face, the refracted shear wave angle is related to the incident angle by

$$\sin \beta = (1430/1483) \sin \alpha = (0.964) \sin \alpha$$

For an incident angle of 30 degrees,

$$\sin \beta = 0.964 \times 0.5 \text{ and } \beta = 28.8 \text{ degrees}$$

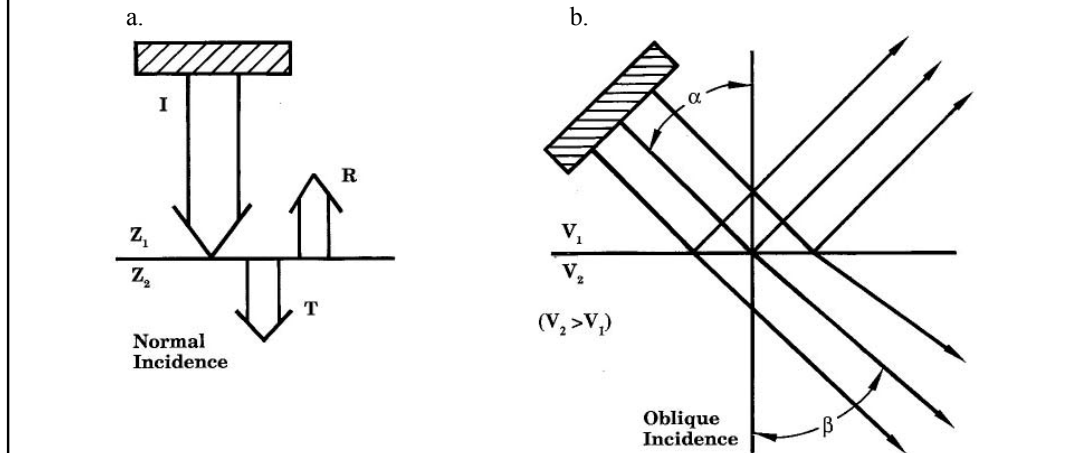
Mode Conversion

It should be noted that the acoustic velocities (V_1 and V_2) used in Equation 1-6 must conform to the modes of wave propagation which exist for each given case. For example, a wave in water (which supports only longitudinal waves) incident on a steel plate at an angle other than 90 *degrees* can generate longitudinal, shear, as well as heavily damped surface or other wave modes, depending on the incident angle and test part geometry. The wave may be totally reflected if the incident angle is sufficiently large. In any case, the waves generated *in the steel* will be refracted in accordance with Snell's Law, whether they are longitudinal or shear waves.

Figure 1.2 shows the distribution of transmitted wave energies as a function of incident angle for a water-aluminum interface. For example, an L-wave with an incidence angle of 8 degrees in water results in (1) a transmitted shear wave in the aluminum with 5 percent of the incident beam energy, (2) a transmitted L-wave with 25 percent and (3) a reflected L-wave with 70 percent of the incident beam energy. It is evident from the figure that for low incidence angles (less than the first critical angle of 14 degrees), more than one mode may be generated in the Aluminum.

¹When Equation 1-5 is expressed for pressure waves rather than the energy contained in the waves, the terms in parentheses are not squared.

Figure 1.1. Incident, reflected, transmitted, and refracted waves at a liquid-solid interface.



Note that the sum of the reflected longitudinal wave energy and the transmitted energy or energies is equal to unity at all angles. The relative energy amplitudes partitioned into the different modes are dependent upon several variables, including each material's acoustic impedance, each wave mode velocity (in both the incident and refracted materials), the incident angle, and the transmitted wave mode(s) refracted angle(s).

Critical Angles

The critical angle for the interface of two media with dissimilar acoustic wave velocities is the

incident angle at which the refracted angle equals 90 degrees (in accordance with Snell's law) and can only occur if the wave mode velocity in the second medium is greater than the wave velocity in the incident medium. It may also be defined as the incident angle beyond which a specific mode cannot occur in the second Medium. In the case of a water-to-steel interface, there are two critical angles derived from Snell's Law. The first occurs at an incident angle of 14.5 degrees for the longitudinal wave. The second occurs at 27.5 degrees for the shear wave. Equation 1-7 can be used to calculate the critical incident angle for any material combination.

$$\alpha_{\text{Crit}} = \sin^{-1} \left(\frac{V_1}{V_2} \right) \quad (\text{Eq. 1-7})$$

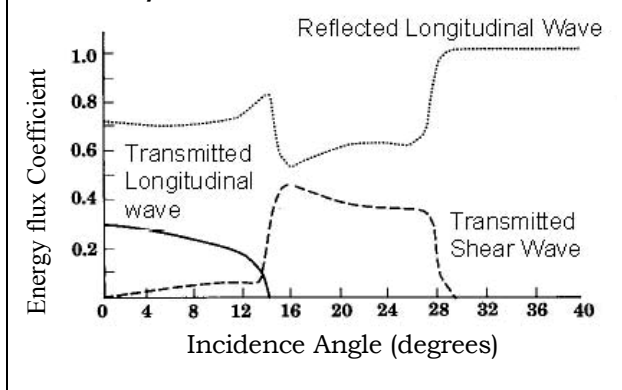
For example, the first critical angle for a water-aluminum interface is calculated using the critical angle equation as

$$\alpha_{\text{Crit}} = \sin^{-1} (1483/6320) = 13.6 \text{ degrees}$$

Diffraction

Plane waves advancing through homogeneous and isotropic elastic media tend to travel in straight ray paths unless a change in media properties is encountered. A flat (much wider than the incident beam)

Figure 1.2. Reflection and transmission coefficients versus incident angle for water/aluminum interface.



interface of differing acoustic properties redirects the incident plane wave in the form of a specularly (mirror-like) reflected or refracted plane wave as discussed above. The assumption in this case is that the interface is large in comparison to the incident beam's dimensions and thus does not encounter any "edges."

On the other hand, when a wave encounters a point reflector (small in comparison to a wavelength), the reflected wave is re-radiated as a spherical wave front. Thus, when a plane wave encounters the edges of reflective interfaces, such as near the tip of a fatigue crack, specular reflections occur along the "flat" surfaces of the crack and cylindrical wavelets are launched from the edges. Since the waves are coherent, i.e., the same frequency (wavelength) and in phase, their redirection into the path of subsequent advancing plane waves results in incident and reflected (scattered) waves interfering, i.e., forming regions of reinforcement (constructive interference) and cancellation (destructive interference).

This "interfering" behavior is characteristic of continuous waves (or pulses From "ringing" ultrasonic transducers) and, when applied to edges and apertures serving as sources of sound beams, is known as wave diffraction. It is they fundamental **basis** for concepts such as transducer beam spread (directivity), near field, wavelength-limited flaw detection sensitivity, and assists in the sizing of discontinuities using dual transducer (crack-tip diffraction) techniques. Figure 1.3 shows examples of plane waves being changed into spherical or cylindrical waves as a result of diffraction from point reflectors, linear edges and (transducer-like) apertures.

Beam spread and the length of the near field for round sound sources may be calculated using Equations 1-8 and 1-9.

$$\sin \phi = 1.2 \frac{\lambda}{D} \quad (\text{Eq. 1-8})$$

$$N = \frac{D^2}{4\lambda} \quad (\text{Eq. 1-9})$$

Where

ϕ is the beam divergence half angle,
 λ is the wavelength in the media,
 f is the frequency of oscillation,

V is the velocity of sound wave propagation,
 D is the diameter of the aperture (transducer),
 N is the length of the Near Field (Fresnel Zone).

Note: The multiplier of 1.2 in Equation 1-8 is for the theoretical null. 1.08 is used for 20 dB down point (10 percent of peak), 0.88 is used for 10 dB down point (32 percent of peak) and 0.7 for 6 dB down point (50 percent of peak).

For example, a 20 mm diameter, L -wave transducer, radiating into steel and operating at a frequency of 2 Mhz, will have a near field given by

$$N = \frac{[20(10)^{-3}]^2 \times 2(10)^6}{4 \times 5.9(10)^3} = \frac{200}{5.9} \times 10^{-3} = 33.9 \text{ mm}$$

and half-beam spread angle given by

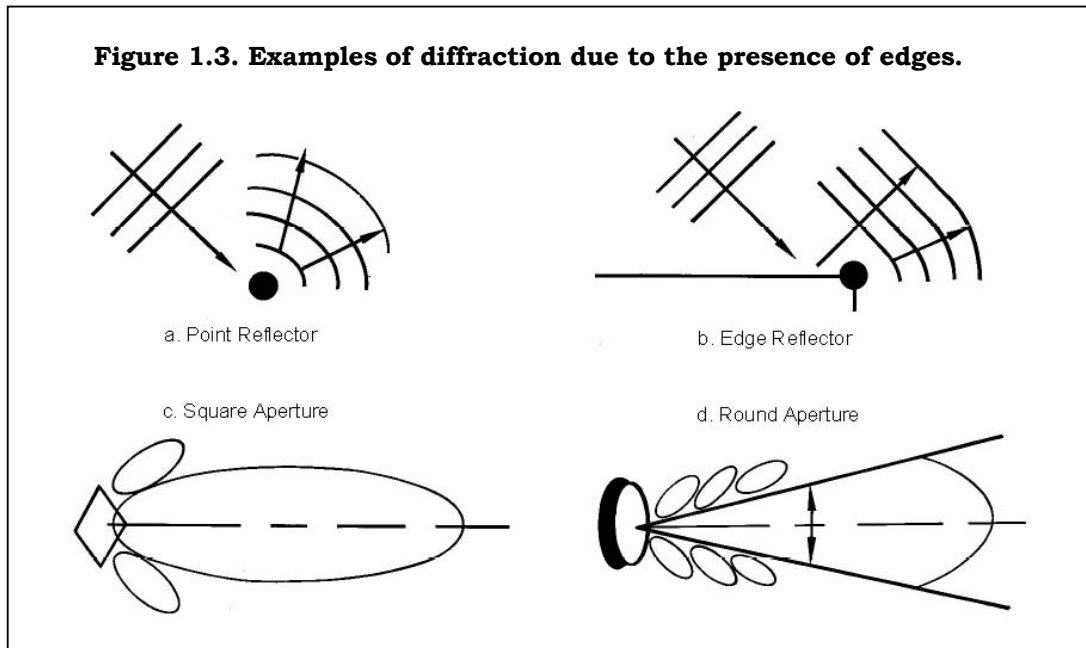
$$\phi = \left\{ \frac{1.2 \times 5.9(10)^3}{20(10)^3 \times 2(10)^6} \right\} = 10.2 \text{ degrees}$$

If the 10 percent peak value was desired rather than the theoretical null, the 1.2 would be changed to 1.08 and ϕ would equal 9.2 degrees. Using the multiplier of 0.7 for the 6 dB down value, the half angle becomes 6 degrees.

Resonance

Another form of wave interference occurs when normally incident (at normal incidence) and reflected plane waves interact (usually within narrow, parallel interfaces). The amplitudes of the superimposed acoustic waves are additive when the phase of the doubly-reflected wave matches that of the incoming incident wave and creates "standing" (as opposed as traveling) acoustic waves. When standing waves occur, the item is said to be in resonance, i.e., resonating. Resonance occurs when the thickness of the item equals half a wavelength² or its multiples, i.e., when $T = V/2F$. This phenomenon occurs when piezoelectric transducers are electrically excited at their characteristic (fundamental resonant) frequency.

Figure 1.3. Examples of diffraction due to the presence of edges.



It also occurs when longitudinal waves travel through thin sheet materials during immersion testing.

Attenuation

Sound waves decrease in intensity as they travel away from their source, due to geometrical spreading, scattering, and absorption. In line-grained, homogeneous, and isotropic elastic materials, the strength of the sound field is affected mainly by the nature of the radiating source and its attendant directivity pattern. Tight patterns (small beam angles) travel farther than widely diverging patterns.

When ultrasonic waves pass through common polycrystalline elastic engineering materials (that are generally homogeneous but contain evenly distributed scatterers, e.g., gas pores, segregated inclusions, and grain boundaries), the waves are partially reflected at each discontinuity and the energy is said to be scattered into many different directions. Thus, the acoustic wave that starts out as a coherent plane wave front becomes partially redirected as it passes through the material.

The relative impact of the presence of scattering sources depends upon their size in comparison to the wavelength of the ultra-sonic wave. Scatterers much smaller than a wavelength are of little consequence. As the scatterer size approaches that of a wavelength, scattering within the material becomes increasingly troublesome. The effects on such signal attenuation can be partially compensated by using longer wavelength (lower frequency) sound sources, usually at the cost of decreased sensitivity to discontinuities and resolution.

Some scatterers, such as columnar grains in stainless steels and laminated composites, exhibit highly anisotropic elastic behavior, in these cases, the incident wave front becomes distorted and often appears to change direction (propagate better in certain preferred directions) in response to the material's anisotropy. This behavior of some materials can totally destroy the usefulness of the UT approach to materials evaluation.

Sound waves in some materials are absorbed by the processes of mechanical hysteresis, internal friction, or other energy **loss** mechanisms. These processes occur in non-elastic materials such as plastics, rubber, lead, and non-rigid coupling materials. As the mechanical wave attempts to propagate through

²If a layer between two differing media has an acoustic impedance equal to the geometric mean of the outer two and its thickness is equal to one-quarter wavelength, 100 percent of the incident acoustic energy, at normal incidence, will be transmitted through the dual interfaces because the interfering waves in the layer combine to serve as an acoustic impedance transformer.

such materials, part of its energy is given up in the form of heat and is not recoverable. Absorption is usually the reason that testing of soft and pliable materials is limited to relatively thin sections.

Attenuation is measured in terms of the energy loss ratio per unit length, e.g., decibels per in. or decibels per meter. Values range from less than 10 dB/m for aluminum to over 100 dB/m or more for some castings, plastics, and concrete.

Table 1.3 shows some typical values of attenuation for common NDT applications. Be aware that attenuation is highly dependent upon

operating frequency and thus **any** stated values must be used with caution.

Because many factors affect the signals re-turned in pulse-echo testing, direct measurement of material attenuation can be quite difficult. Detected signals depend heavily upon operating frequency, boundary conditions, and waveform geometry (plane or other), as well as the precise nature of the materials being evaluated. Materials are highly variable due to their thermal history, balance of alloying or other integral constituents (aggregate, fibers, matrix uniformity, water/void content, to name a few), as well as mechanical processing (forging, rolling, extruding, and the preferential directional nature of these processes).

Table 1.3. Attenuation Values for Common Materials

Nature of Material	Attenuation* (dB/m)	Principal Cause
Normalized Steel	70	Scatter
Aluminum, 6061-T6511	90	Scatter
Stainless Steel, 3XX	110	Scatter/Redirection
Plastic (clear acrylic)	380	Absorption

*Frequency of 2.25 MHz, Longitudinal wave mode

Chapter 1 Review Questions

- Q.1-1 Sound waves continue to travel _____.
 A. until they are reflected by material surfaces
 B. gradually dissipating by the effects of beam spread
 C. gradually dissipating by scattering and absorption
 D. all of the above
- Q.1-2 Wavelength may be defined as _____.
 A. frequency divided by velocity
 B. the distance along a wave train from peak to trough
 C. the distance from one point to the next identical point along a wavetrain
 D. the distance along a wavetrain from an area of high particle motion to one of low particle motion
- Q.1-3 To determine wavelength
 A. multiply velocity by frequency
 B. divide velocity by frequency
 C. divide frequency by velocity
 D. none of the above
- Q.1-4 The wavelength of a 5 MHz sound wave in water is _____. ($V_L = 1.48(10)^5$ cm/sec)
 A. 0.01 in.
 B. 0.10 in.
 C. 0.296 m
 D. 3.00 mm
- Q.1-5 Thickness resonance occurs when transducers and test parts are excited at a frequency equal to _____ where V = sound velocity and T = item thickness.
 A. $2T/V$
 B. $T/2V$
 C. $V/2T$
 D. $2VT$
- Q.1-6 The equations that show V_L and V_T being dependent on elastic properties suggest that
 A. materials with higher densities will usually have higher acoustic velocities
 B. materials with higher moduli will usually have higher velocities
 C. wave velocities rely mostly upon the ratios of elastic moduli to material density
 D. V_T will always be one-half of V_L in the same material
- Q.1-7 Velocity measurements in a material revealed that the velocity decreased as frequency increased. This material is called _____.
 A. dissipated
 B. discontinuous
 C. dispersive
 D. degenerative
- Q.1-8 Plate thickness = 25.4 mm, pulse-echo, straight beam measured elapsed time = 8 microseconds. What is the most likely material?
 A. carbon steel
 B. lead
 C. titanium
 D. aluminum
- Q.1-9 It can be deduced from Table 1.2 that the densities of _____
 A. water and plexiglasTM are in the ratio of 1.16: 1
 B. steel and aluminum are in the ratio of 2.8:1
 C. quartz and aluminum are in the ratio of 1.05:1
 D. all of the above
- Q.1-10 The acoustic energy reflected at a plexiglasTM-quartz interface is equal to
 A. 64 percent
 B. 41 percent
 C. 22 percent
 D. 52 percent
- Q.1-11 The acoustic energy transmitted through a plexiglasTM-water interface is equal to _____.
 A. 87 percent
 B. 36 percent
 C. 13 percent
 D. 64 percent
- Q.1-12 The first critical angle at a water-plexiglasTM interface will be _____.
 A. 16 degrees
 B. 33 degrees
 C. 22 degrees
 D. none of the above
- Q.1-13 The second critical angle at a water-plexiglasTM interface will be _____.
 A. 22 degrees
 B. 33 degrees
 C. 67 degrees
 D. none of the above

Q.1-14 The incident angle needed in immersion testing to develop a 70-degree shear wave in plexiglas™ equals _____

- A. 83 degrees
- B. 77 degrees
- C. 74 degrees
- D. 65 degrees

Q.1-15 Figure 1.2 shows the partition of incident and transmitted waves at a water-aluminum interface. At an incidence angle of 20 degrees, the reflected wave and transmitted waves are respectively _____

- A. 60 percent and 40 percent
- B. 40 percent and 60 percent
- C. 1/3 and 2/3
- D. 80 percent and 20 percent

Q.1-16 From Figure 1.2 it is evident that the sum of the incident wave's partitions (transmitted and reflected) is _____

- A. highly irregular at low angles, but constant above 30 degrees
- B. lower at angles between 16 and 26 degrees
- C. rarely more than 0.8
- D. always equal to unity

QA-17 The principal attenuation modes are _.

- A. absorption, scatter, beam spread
- B. beam spread, collimation, scatter
- C. scatter, absorption, focusing
- D. scatter, beam spread, adhesion

Q.1-18 Attenuation caused by scattering

- A. increases with increased frequency and grain size
- B. decreases with increased frequency and grain size
- C. increases with higher frequency and decreases with larger grain size
- D. decreases with higher frequency and decreases with larger grain size

Q.1-19 In very fine-grain, isotropic crystalline material, the principal loss mechanism at 2 MHz is

- A. scatter
- B. mechanical hysteresis
- C. beam spread
- D. absorption

Q. 1-20 Two plates yield different back wall reflections in pulse-echo testing (18 dB) with their only apparent difference being in the second material's void content. The plates are both 3 in. thick. What is the effective change in acoustic attenuation between the first and second plate?

- A. 3 dB/in
- B. 6 dB/in
- C. 1.8 dB/in
- D. none of the above

Q.1-21 The equation, $\sin p = 0.7\lambda/D$, describes

- A. beam spread angle at 50 percent decrease in signal from the centerline value
- B. one-half the beam spread angle at 50 percent decrease in signal from the centerline value
- C. one-half the beam spread angle at 20 percent decrease in signal from the centerline value
- D. one-half the beam spread angle at 100 percent decrease in signal from the centerline value

Q.1-22 The beam spread half-angle in the far field of a 1 in. diameter transducer sending 5 MHz longitudinal waves into a plexiglas™ block is

- A. 0.5 degrees
- B. 1.5 degrees
- C. 3.1 degrees
- D. 6.2 degrees

Q.] -23 The near field of a round 112 in. diameter contact L-wave transducer being used on a steel test part operating at 3 Mhz is _____

- A. 0.5 in.
- B. 1 in.
- C. 1 cm
- D. 2 cm

Q.1-24 The depth of penetration of the sound beam into a material can be increased by

- A. using a higher frequency
- B. using a longer wavelength
- C. using a smaller transducer
- D. using a lower frequency and a larger transducer

~_J

Chapter 2

Equipment

Chapter 2

Equipment

Basic Instrumentation

The basic electronic instrument used in pulsed ultrasonic testing contains a source of voltage spikes (to activate the sound source, i.e., the pulser) and a display mechanism that permits interpretation of received ultrasonic acoustic impulses, i.e., the sweep generator, receiver and cathode ray tube (CRT). A block diagram of the basic unit is shown in Figure 2.1.

Several operations are synchronized by the clock (timer) circuitry which triggers appropriate components to initiate actions including the pulser (that activates the transducer), the sweep

generator (that forces the electron beam within the cathode ray tube to move horizontally across the screen), and other special circuits as needed including markers, sweep delays, gates, electronic distance amplitude correction (DAC) units, and other support circuits.

Pulse signals from the receiver search unit³ are amplified to a level compatible with the CRT

³The term pulse is used in two contexts in ultrasonic NDT systems. The electronic system sends an exciting electrical "pulse" to the transducer being used to emit the ultrasonic wave. This electrical pulse is usually a unidirectional spike with a fast rise-time. The resulting acoustic "wave packet" emitted by the transducer is the ultrasonic pulse, characterized by a predominant central frequency at the transducer's natural thickness resonance.

Figure 2.1. Block diagram of basic pulse-echo ultrasonic instrument

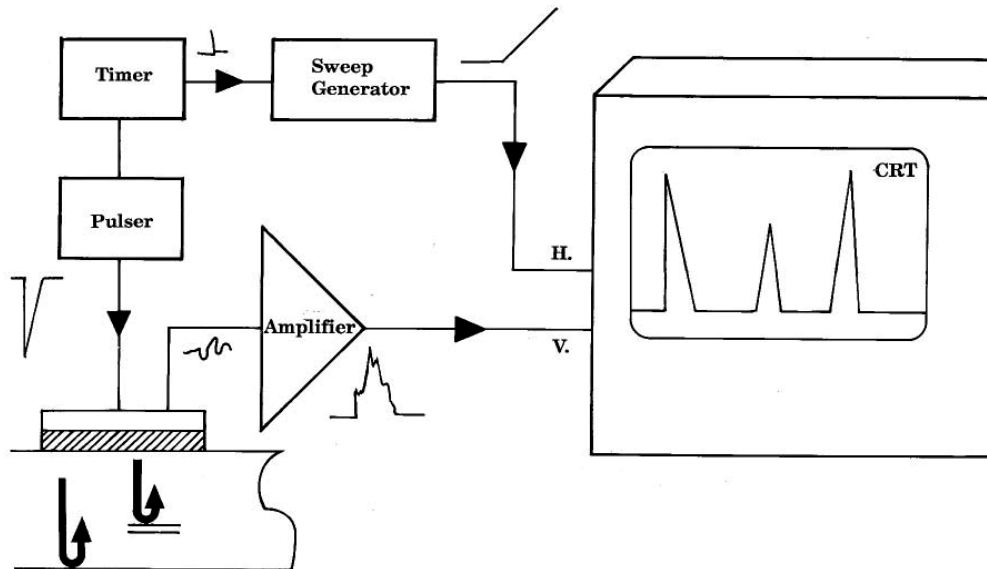


Table 2.1. Instrumentation Controls Effects

Instrument Control	Comments on Signal Response
Pulser	
Pulse Length (Damping)	If short, improves depth resolution; If long, improves penetration
Repetition Rate	If high, brightens images-but may cause wrap-around "ghost" signals
Receiver	
Frequency Response	Wide Band-faithful reproduction of signal, higher background noise Narrow Band-higher sensitivity, smoothed signals, requires matched (tuned) system
Gain	If high, improves sensitivity, higher background noise
Display	
Sweep	
Material Adjust	Calibration critical for depth information
Delay	Permits "spreading" of echo pulses for detailed analysis
Reject	Lowers dynamic range, suppresses low-level noise, alters vertical linearity
Smoothing	Suppresses detailed pulse structure
Output (Alarm, Record)	
Gates	
Time Window (Delay, Width)	Selects portion of display for analysis, gate may distort pulses
Threshold	Sets output sensitivity
Polarity	Permits positive and negative images, allows triggering on both increasing and decreasing pulses

and appear as vertical excursions of the electron beam sweeping across the screen in response to the sweep generator. The received signals are often processed to enhance interpretation through the use of filters (that limit spurious background noise and smooth the appearance of the pulses), rectifiers (that change the oscillatory radio-frequency [RF] signals to uni-directional spikes), and clipping circuits (that reject low-level background signals). The final signals are passed on to the vertical deflection plates of the CRT and produce the time-delayed echo signals interpreted by the UT operator, commonly referred to as an A-scan (signal amplitude displayed as a function of time).

All of these functions are within the control of the operator and their collective settings represent the "setup" of the instrument. Table 2.1 lists the variables under the control of the

operator and the impact they have on the validity of an ultrasonic test. If desired, a particular portion of the trace may be "gated" and the signal within the gate sent to some external device, i.e., an alarm or recording device, which registers the presence (or absence) of echo signals-that are being sought (or for which their loss signifies a potential problem exists).

Characteristics of the initial pulse (shape and frequency content) are carried forward through-out the system, to the transducer, the test item, back to the transducer, the receiver, the gate, and the CRT. In essence, the information content of the initial pulse is modified by each of these items and it is the result of this collective signal processing that appears on the screen of the CRT.

The initial pulse may range from several hundred to over 1000 volts and have a very short

rise-time. In other systems, the initial pulse may represent a portion of a sinusoidal oscillation that is tuned to correspond to the natural frequency of the transducer. The sinusoidal excitation is often used where longer duration pulses are needed to penetrate highly attenuative materials such as rubber and concrete.

Signals from the receiving transducer (usually in the millivolt range) are too small to be directly sent to the CRT. Both linear and logarithmic amplifiers are used to raise signal levels needed to drive the CRT plates. These amplifiers, located in the receiver sections of the A-scan units, must be able to produce output signals that are linearly related to the input signals and which supply signal processing intended to assist the operator in interpreting the signals displayed on the CRT.

Amplifiers may raise incoming signals to a maximum level, followed by precision attenuators that decrease the signal strength to CRT-usable levels, i.e., capable of being positioned on the CRT screen face, or they may be capable of changing amplification ratios in direct response to the "Gain" control.

Discrete attenuators (which have a logarithmic response) are currently used due to their ease of precise construction and simple means for altering signal levels which extend beyond the viewing range of the CRT screen. Their extensive use has made "decibel notation" a part of the standard terminology used in describing changes in signal levels, e.g., receiver gain and material attenuation.

Equation 2-1 (ratios to decibels) shows the relationship between the ratio of two pulse amplitudes (A_2 and A_1) and their equivalence expressed in decibel notation (N_{db}).

$$N_{db} = 20 \log_{10} (A_2/A_1) \quad (\text{Eq. 2-1})$$

Inversion of this equation results in the useful expression

$$A_2/A_1 = 10^{N/20}$$

where a change of 20 dB, i.e., $N = 20$,

$$\text{makes } 10^{N/20} = 10^1 = 10$$

Thus 20 dB is equivalent to a ratio of 10:1.

Signals may be displayed as RE waveforms, representing a close replica of the acoustic wave as it was detected by the receiving transducer, or as video waveforms, (half- or full-wave rectified), used to double the effective viewing range of the CRT screen (bottom to top rather than centerline to top/bottom), but suppressing the phase information that is available in the RF presentations.

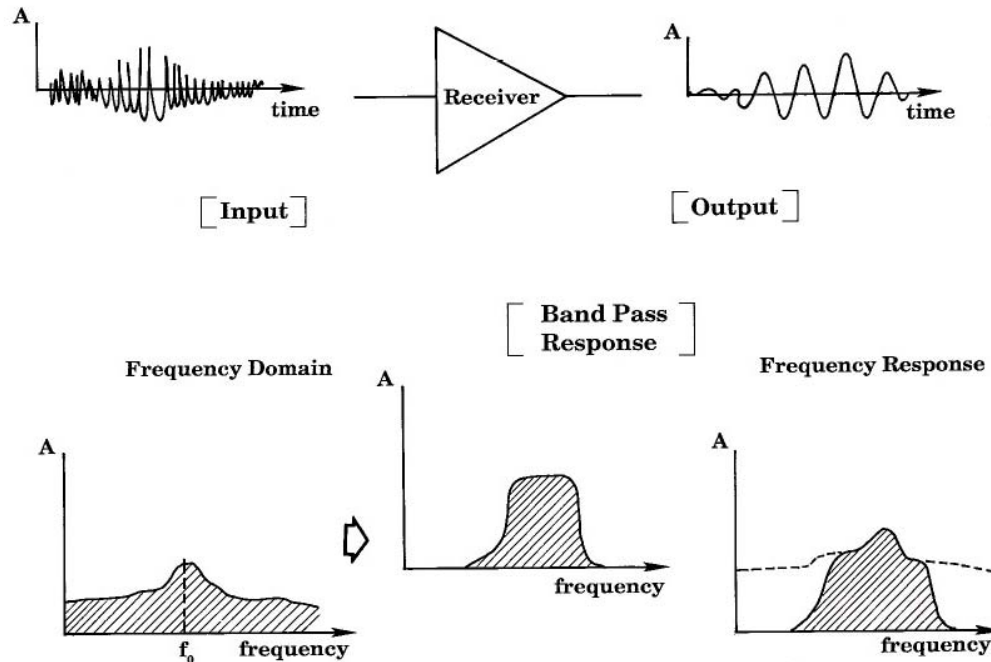
To enhance the ability to accurately identify and assess the nature of the received ultrasonic pulses, particularly when there exists an excessive amount of background signals, various means of signal processing are used. Both tuned receivers (narrow-band instruments) and low pass filters are used to selectively suppress portions of the received spectrum of signal frequencies which do not contain useful information from the test material.

Linear systems, such as the ultrasonic instrument's receiver section (as well as each of the elements of the overall system), are characterized by the manner in which they affect incoming signals. A common approach is to start with the frequency content of the incoming signal (from the receiving transducer) and to describe how that spectrum of frequencies is altered as a result of passing through the linear system.

When both useful target information (which may be predominantly contained in a narrow band of frequencies generated by the sending transducer) and background noise (which may be distributed randomly over a broad spectrum of frequencies) are present in the signal entering the receiver, selective passing of the frequencies of interest emphasizes the signals of interest while suppressing the others which interfere with interpretation of the CRT display.

When an ultrasonic instrument is described as being broad-banded, that means a very wide array of frequencies can be processed through

Figure 2.2. Comparison of time domain and frequency domain representations of typical signals found in ultrasonic testing.



the instrument with a minimum of alteration, i.e., the signal observed on the CRT screen is a close, but amplified, representation of the electrical signal measured at the receiving transducer. Thus both useful signals and background noise are present and the signal-to-noise ratio (SIN) may not be very good. The shape and amplitudes of the signals, however, tend to be an accurate representation of the received response from the transducer,

A narrow-banded instrument, on the other hand, suppresses that portion of the frequency content of the incoming signal that is outside (above or below) the "pass" frequency band. With the high-frequency noise suppressed, the gain of the instrument can be increased, leading to an improved sensitivity. However, the shape and relative amplitudes of pulse frequency components are often altered. Figure 2.2 graphically shows these *effects* for a typical ultrasonic signal.

Transducers and Coupling

A transducer, as applied to ultrasonic testing, is the means by which electrical energy is converted into acoustic energy and back again. The device, adapted for UT, has been called a probe, a search unit, a crystal, and a transducer.⁴ A probe or search unit may contain one or more transducers, plus facing/backing materials and connectors in order to meet a specific UT design need.

A critical element of each search unit is the transducer's active material. Commonly used materials generate stress waves when they are subjected to electrical stimuli, i.e., piezoelectrics. These materials are characterized by their conversion factors (electrical to/from mechanical), thermal/mechanical stability, and other physical/chemical features. Table 2.2 lists many of the

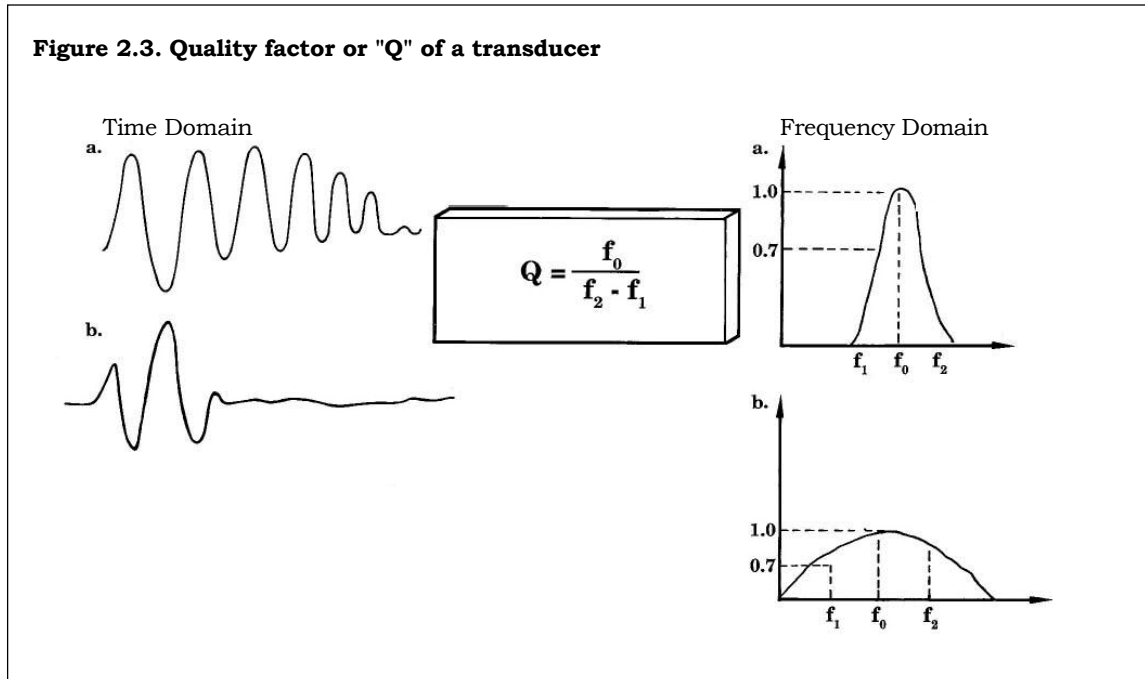
⁴The term transducer is generic in that it applies to any device that converts one form of energy into another, e.g., light bulbs, electric heaters, and solar collectors.

Table 2.2. Piezoelectric Material Characteristics

Material	Efficiency			(Z)	Critical Temp (°C)	Displacement (d_{33})	Electrical (g33)	Density P	Note
	T	R	T/R						
Quartz X-cut	1	1	1	15.2	576	2.3	57	2.65	(1)
PZT 5 Lead Zirconate Titanate	70	0.21	14.6	33	193-365	374-593	20-25	7.5	(2)
BaTi Barium Titanate	8.4	--	--	31.2	115-150	125-190	14-21	5.4	(2)
PMN Lead Metaniobate	32	--	--	20.5	550	80-85	32-42	6.2	(2)
LSH Lithium Sulfate Hydrate	6.9	-2.0	--	11.2	75	15-16	156-175	2.06	(3)
LN Lithium Niobate	2.8	0.54	1.51	34	--	6	23	4.64	
PVDF Poly (vinylidene Fluoride)	6.9	1.35	9.3	4.1	165-180	14	140-210	1.76	(4)

Notes:

- 1) Mechanically and chemically stable; X-cut yields longitudinal wave motion while Y-cut yields distortional transverse waves.
- 2) Ferroelectric ceramic requiring poling and subject to extensive cross-mode coupling.
- 3) Soluble in water, R estimated at -2.
- 4) Flexible polymer.

Figure 2.3. Quality factor or "Q" of a transducer

materials used and some of their salient features. The critical temperature is the temperature above which the material loses its piezoelectric characteristic. It may be the depoling temperature of the ferroelectrics, the decomposition temperature for the lithium sulfate or the Curie Temperature for the quartz.

The quality factor, or "Q," of tuned circuits, search units or individual transducer elements is a performance measure of their frequency selectivity. It is the ratio of the search unit's fundamental (resonance) frequency (f_1) to its band-width ($f_2 - f_1$) at the 3 dB down points (0.707) and shown in Figure 2.3.

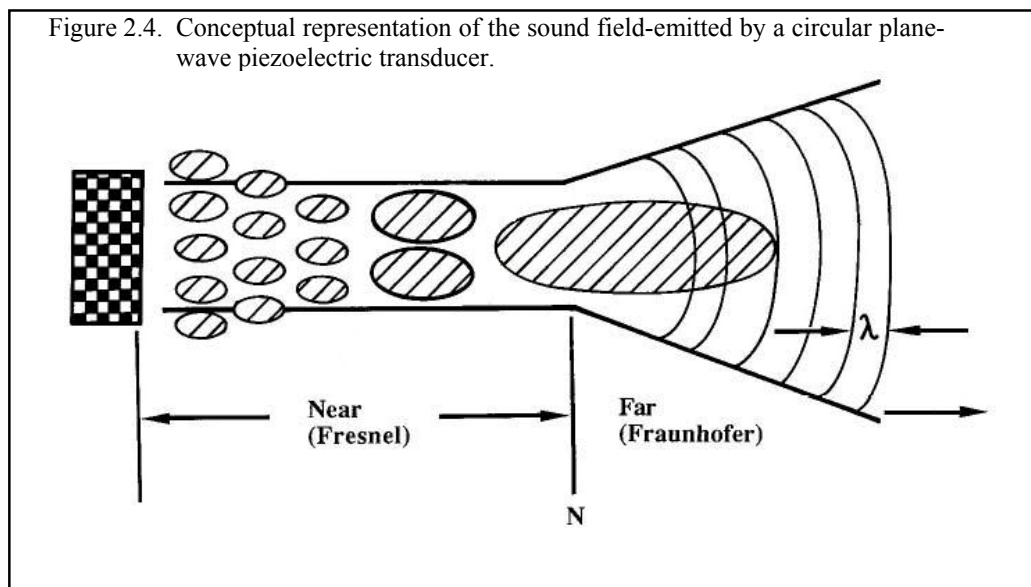
The ratio of the acoustic impedance of the transducer and its facing materials governs how well the sound from the transducer can be coupled into the material and/or the backing material. From the table of piezoelectric material characteristics, it is apparent that none of the materials is an ideal match for NDT. Thus dual transducer search units are sometimes made such that the transmitter and receiver are made of different transducer materials in order to take advantage of their respective strengths and to minimize their weaknesses.

As a result of diffraction effects, the sound beam emitted from search units tends to spread with increasing distance away from the sound source. The sound beam exiting from a trans-

ducer can be separated into two zones or areas. The Near (Fresnel) Field and the Far (Fraunhofer) Field are shown in Figure 2.4 with the shaded areas representing regions of relatively high pressure.

The near field is the region directly adjacent to the transducer and characterized as a collection of symmetrical high and low pressure regions caused by interfering wavefronts emanating from a continuous, or near continuous, sound source. Huygen's principle treats the transducer face as a series of point sources of sound, which interfere with each other's wave-lets throughout the near field. Each point source emits spherical wavefronts which start out in phase at the transducer surface. At observation points somewhat removed from the plane wave source (the transducer face), wavefronts from various point sources (separated laterally from each other) interfere as a result of the differing distances the waves had to travel in order to reach the observation point. Both high and low pressure zones result, depending on whether the superimposed aggregate of interfering waves are constructive (in phase) or destructive (180 degrees out of phase).

As a special case, the variation in beam pressure as a function of distance from a circular transducer face and along its major axis is given by Equation 2-2.



$$Y_m^+ = \frac{D^2 - \lambda^2(2m+1)^2}{4\lambda(2m+1)}; m=0, \pm 1, \pm 2, \dots \pm m$$

(Eq. 2-2)

where

- Y^+ is the position of maxima along central axis,
- D is the diameter of a circular radiator, and
- λ is the wavelength of sound in the medium.

Since λ^2 is insignificant compared to D^2 for most ultrasonic testing frequencies, particularly in water at the last maximum, ($m = 0$), Equation 2-2 becomes:

$$Y_0^+ = \frac{D^2}{4\lambda}$$

(Eq. 2-3)

This point defines the end of the near field and is the same expression as given in Equation 1-9.

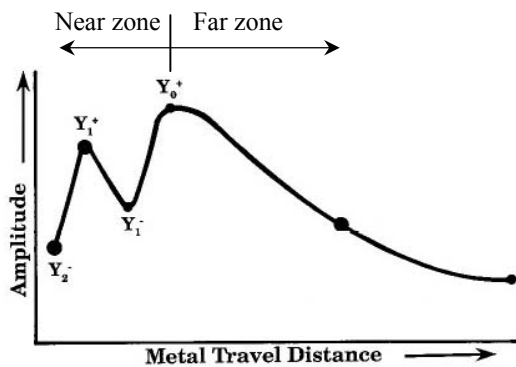
At distances well removed from the sound source (the far field), the waves no longer interfere with each other (since the difference in travel path to the center and edge of the source are much less than a wavelength) and the sound field is reduced in strength in a monotonic manner. In the far field, the beam is diverging and has a spherically shaped wave front as if radiating from a point source. The far field sound field intensity decreases due to both the distance from the source and the diffraction based directivity

(beam shape) factor. Maximum pressure amplitudes exist along the beam centerline. Figure 2.5 shows a graphical representation of a typical distance-amplitude variation for a straight beam transducer.

The penetration, depth resolution, and sensitivity of an ultrasonic system are strongly dependent upon the nature of the pulse emitted by the transducer. High-frequency, short-duration pulses exhibit better depth resolution but allow less penetration into common engineering materials. A short time-duration pulse of only a few cycles is known as a broadband pulse because its frequency-domain equivalent bandwidth is large. Such pulses exhibit good depth resolution.

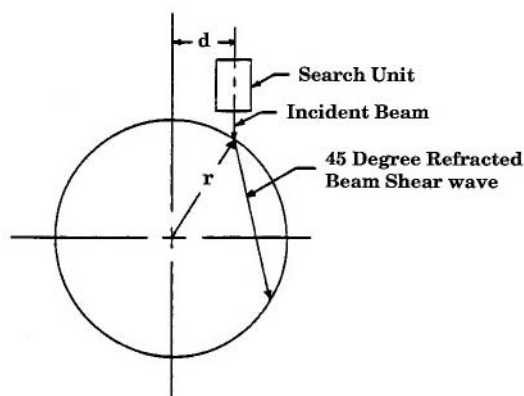
Most search units are constructed with a backing material bonded to the rear face of the transducer that provides strength and damping for the transducer element. This backing material is usually an epoxy, preferentially filled with tungsten or some other high-density powder that increases the effective density of the epoxy to something approaching that of the transducer element. Thus the tungsten assists in matching the acoustic impedance of the transducer (which is usually relatively high) to the backing material. When the backing is in intimate contact with the transducer, the pulse duration is shortened to a few oscillations and decreased in peak signal amplitude. The pulse energy is therefore partitioned between the item being tested and the backing material (which removes the rearward-directed waves and absorbs them in the coarse-surfaced epoxy).

Figure 2.5 Typical straight beam DAC curve



Search units come in many types and styles depending upon their purpose. Most search units use an L-wave-generating sound source. "Normal" or "straight" beam search units, the colloquial names given to longitudinal wave transducers when used in contact testing, are so named because the sound beam is directed into the material in a perpendicular (normal) direction. These units generate longitudinal waves in the material and are used for thickness gaging and flaw detection of laminar-type flaws. Both contact and immersion search units are readily available. To improve near-surface resolution

Figure 2.6. Introduction of shear waves through mode conversion.



and to decrease noise, standoff devices and dual crystal units may be used.

Transverse (shear) waves are introduced into test materials by inclining the incident L-wave beyond the first critical angle, yet short of the second critical angle. In immersion testing, this is done by changing the angle of the search unit manipulator. In the case of cylindrical products, shear waves can be generated by offsetting the transducer from the centerline of the pipe or round bar being inspected. Figure 2.6 shows a typical testing configuration for solid round materials. For the case of a 45-degree refracted beam, a rule of thumb for the displacement d is $1/6$ the rod diameter.

In contact testing, the so-called angle-beam search units cause the beam to proceed through the material in a plane that is normal to the surface and typically at angles of 45, 60, and 70 degrees. Transverse waves are introduced by precut wedges which, when in contact with metals, generate shear waves through mode conversion at the wedge-metal interface. (See Figure 2.7).

High-frequency (ultrasonic) sound waves: travel poorly in air and not at all in a vacuum. In order for the mechanical energy generated by a transducer to be transmitted into the medium to be examined, a liquid that bridges the gap between the transducer and the test piece is used

to couple the acoustic wave to the item being tested. This liquid is the "couplant" often mentioned in UT. When immersion testing is being conducted, the part is immersed in water which serves as the couplant. When contact testing is being conducted, liquids with varying viscosities are used in order to avoid unnecessary runoff, particularly with materials with very rough contact surfaces or when testing overhead or vertically.

Liquids transmit longitudinal sound waves rather well, but because of their lack of any significant shear moduli (except for highly viscous materials), they do not transmit shear waves.⁵ Couplants should wet the surfaces of both the search unit and the material under test in order to exclude any air that might become entrapped in the gap(s) between the transducer and the test piece. Couplants must be inert to both the test material and the search unit.

Contact couplants must have many desirable properties including: wetability (crystal, shoe, and test materials), proper viscosity, low cost, removability, non-corrosive and non-toxic properties, low attenuation, and an acoustic impedance that matches well with the other materials. In selecting the couplant, the operator must consider all or most of these factors depending on the surface finish, type of material, temperature, surface orientation, and availability. The couplant should be spread in a thin, uniform film between the transducer and the material under test. Rough surfaces and vertical or overhead surfaces require a higher viscosity couplant than smooth, horizontal surfaces. Materials used in this application include various grades and viscosities of oil, Glycerine, paste couplants using cellulose gum (which tend to evaporate leaving little or no residue) and various miscible mixtures of these materials using water as a thinner.

Because stainless steels and other high-nickel alloys are susceptible to stress-related corrosion

⁵Because the acoustic impedance of air is so much different than that of the commonly used transducers and test materials, its presence reflects an objectionable amount of acoustic energy at coupling interfaces. but is the main reason ultrasonic testing is effective with air-filled cracks and similar critical discontinuities.

cracking in the presence of sulphur and chlorine, the use of couplants containing even trace amounts of these materials is prohibited. Most commercial couplant manufacturers provide certificates of conformance regarding absence of these elements, upon request.

In a few highly specialized applications, dry couplants, such as a sheet of elastomer, have been used. Bonding the transducer to the test item, usually in distributed materials characterization studies, is an accepted practice.

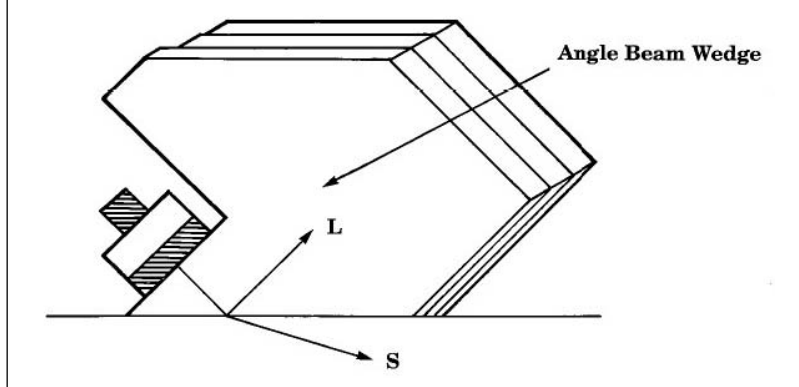
High pressure and intermittent contact without a coupling medium, has also been used on high-temperature steel ingots. Although these approaches have been reported in the literature, they are not commonly used in production applications.

Water is the most widely used couplant for immersion testing. It is inexpensive, plentiful, and relatively inert to the materials involved. It is sometimes necessary to add wetting agents, anti-rust additives and anti-fouling agents to the water to prevent corrosion, assure absence of air bubbles on test part surfaces, and avoid the growth of bacteria and algae. Bubbles are removed from both the transducer face and the material under examination by regular wiping of these surfaces or by water jet.

In immersion testing, the sound beam can be focused using piano-concave lenses, producing a higher, more concentrated beam that results in better lateral (spatial) resolution in the vicinity of the focal zone. This focusing moves the last peak of the near field closer to the transducer than that found with a flat transducer. Lenses may be formed from epoxy or other plastic materials, e.g., polystyrene. The focal length is determined using Equation 2-4.

$$R = F \frac{(n-1)}{n} \quad (\text{Eq. 2-4})$$

Figure 2.7. Contact shear wave transducer design.



Where

R is the lens radius of curvature,

F is the focal length in water,

n is the ratio of the acoustic L-wave velocities,

$$n = V_1/V_2 \text{ where}$$

V_1 is the longitudinal velocity in epoxy,

V_2 is the velocity in water.

For example, to get a focal length of 2.5 in. using a *plexiglas*TM lens and water, the radius of curvature equation uses a velocity ratio of $n = 1.84$ and the equation becomes

$$R = 2.5 (0.84/1.84) = 1.14 \text{ in.}$$

Focusing has three principal advantages. First, the energy at the focal point is increased, which increases the sensitivity or signal amplitude. Second, sensitivity to reflectors above and below the focal point is decreased, which reduces the "noise." Third, the lateral resolution is increased because the focal point is normally quite small, permitting increased definition of the size and shape of the reflector.

Focusing is useful in applications such as the examination of a bondline between two materials, e.g., a composite material bonded to an aluminum frame. When examined from the composite side, there are many echoes from within the composite which interfere with the desired interface signal; however, focusing at the bondline reduces the interference and increases

system sensitivity and resolution at the bond line depth.

Where a shape other than a simple round or square transducer is needed, particularly for larger-area sound field sources, transducer elements can be assembled into mosaics and excited either as a single unit or in special timing sequences. Mosaic assemblies may be linear, circular, or any combination of these geometries. With properly timed sequences of exciting pulses, these units can function as a linear array (with steerable beam angles) or as transducers with a variable focus capability. Paint brush transducers are usually a single element search-unit with a large length-to-width ratio and are used to sweep across large segments of material in a single pass. The sound beam is broad and the lateral resolution and flaw sensitivity is not as good as smaller transducers.

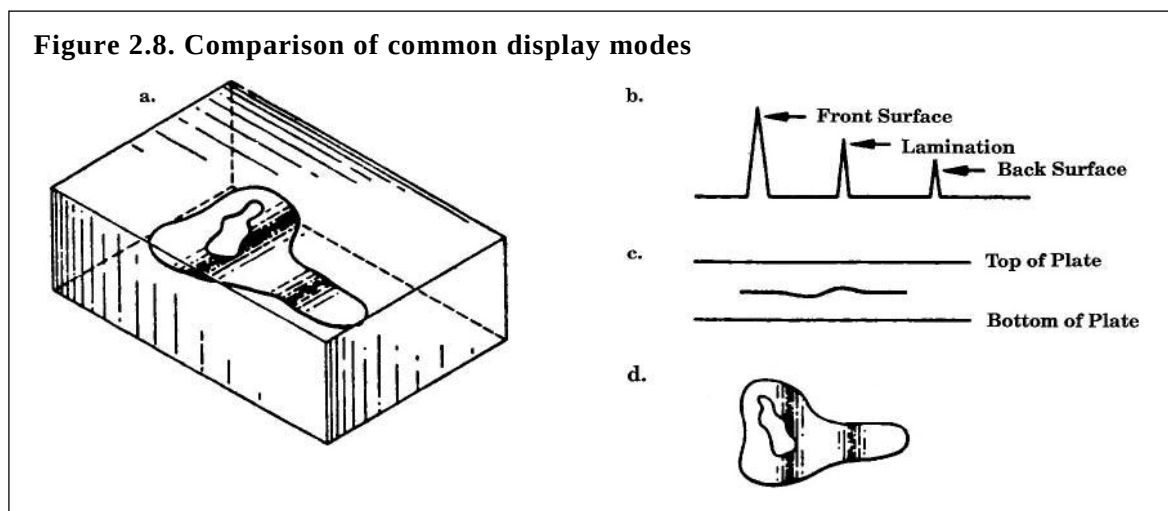
Special Equipment Features.

The basic electronic pulser/receiver display units are augmented with special features intended to assist operators in easing the burden of maintaining a high level of alertness during the often uninteresting process of conducting routine inspections, particularly of regular shapes during original manufacture, as well as obtaining some type of permanent record of the results of the inspection.

A-scan information represents the material condition through which the sound beam is passing. The fundamental A-scan display, although highly informative regarding material homogeneity, does not yield information regarding the spatial distribution of ultrasonic wave reflectors until it is connected with scanning mechanisms that can supply the physical location of the transducer in conjunction with the reflector data obtained with the A-scan unit.

When cross-sectional information is recorded using a rectilinear B-scan system, it is the time of arrival of a pulse (vertical direction) plotted as a function of the transducer position (horizontal direction) that is displayed. Circular objects are often displayed using a curvilinear coordinate system which displays time of pulse arrival in the radial direction (measured from the transducer) and with transducer location following the surface contour of the test object.

When plan views of objects are needed, the C-scan system is used and is particularly effective for flat materials including honeycomb panels, rolled products, and adhesively bonded or laminated composites. The C-scan is developed using a raster scan pattern (X vs. Y) over the test part surface. The presence of questionable conditions is detected by gating signals falling within the thickness of the part (or monitoring loss of transmission) as a function of location. C-scanning systems use either storage



oscilloscopes or other recording devices, coupled to automatic scanning systems which represent a "plan," i.e., map, view of the part, similar to the view produced in radiography. Figure 2.8 shows examples of these display options.

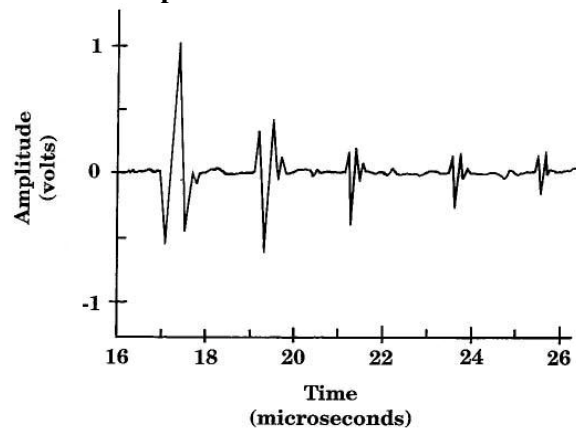
Accumulation of data for display in the form of B- or C-scans is extracted using electronic "gates." Gates are circuits which extract time and amplitude information of selected signals on the A-scan presentation and feed these as analog data to other signal processing or display circuits or devices. The start time and duration of the gate are operator selectable. CRT representations of the gate are raised or depressed baselines, a horizontal bar, or two vertical lines. Available with adjustable thresholds, gates can be set to record signals which either exceed or drop below specified threshold settings.

Details of received signals can be seen and/or disregarded through use of the RF display and the Reject controls, respectively. The RF display shown in Figure 2.9 is representative of the actual ultra-sonic stress pulses received. Of interest is the fact that in this mode, the initial polarity of the stress pulse can be seen as the first oscillation being displaced downward (as in the initial pulse at 0.4 micro-seconds), as opposed to the initial oscillation excursion being upward on the pulses received after being reflected from a free

boundary (at 1.4, 2.5, 3.6, and 4.6 micro-seconds). This phase reversal can be used to discriminate between "hard" boundaries (high impedance) and "soft" boundaries (low impedance such as air).

The reject control, on the other hand, tends to discriminate against low-level signals, through use of a threshold, below which no information is made available to the operator. Early versions of the reject circuitry tended to alter the vertical linearity of CRT systems; however, this condition has been corrected in several of the newer digital flaw detector instruments.

Figure 2.9. RF display showing phase reversal upon reflection.



Chapter 2 Review Questions

Q.2-1 Barium titanate is a piezoelectric material which _____

- A. is naturally piezoelectric
- B. is piezoelectric at temperatures above the critical temperature
- C. has a high acoustic impedance
- D. is highly soluble in water

Q.2-2 During an immersion test, numerous bubbles are noted in the water attached to the test item. These bubbles are small relative to the part size. What steps should the operator take?

- A. remove the bubbles by blowing them off with an air hose
- B. ignore the bubbles because they are small and will not interfere with the test
- C. remove the bubbles, with brush or other mechanical means such as rubbing with the hand while the test is stopped
- D. count the bubbles and mark their echoes on the test record

Q.2-3 A couplant is needed for a test on a hot steel plate (250 °F). Which of the following materials can be used?

- A. water
- B. mercury
- C. tractor oil
- D. none of the above

Q.2-4 A couplant is needed for a test on stainless steel welds. Numerous couplants are available. Which should be chosen and why?

- A. a couplant free of chlorine because this element corrodes stainless steel
- B. glycerine because it is nonflammable
- C. oil because it is easily removed
- D. water because stainless steel does not corrode in water

Q.2-5 A 5 MHz, 0.5 in. diameter, flat search. unit in water has a near field length of approximately

- A. 7 in.
- B. 2 in.
- C. 3-113 in.
- D. 5-112 in.

Q.2-6 A concave lens on a transducer will **result** in the near field in water being _____

- A. twice as long as with a flat lens
- B. three times as long as with a flat lens
- C. the same length as with a flat lens
- D. shorter than with a flat lens

Q.2-7 A 10 MHz, 0.5 in. dia., search unit is placed on steel and acrylic plastic in succession. The beam spread in these two materials is approximately ____

- A. 3 and 1.5 degrees, respectively
- B. 1.5 and 3 degrees, respectively
- C. equal in the two materials
- D. less than the beam spread of a 15 MHz search unit of the same diameter

Q.2-8 Focused transducers are useful *because* the_

- A. smaller beam diameter increases the number of scans required to examine an object
- B. lateral resolution is improved
- C. lateral resolution is unimportant
- D. focal point is located beyond the end of the near field length of a similar, unfocused transducer

Q.2-9 In spite of the fact that a long pulse has better depth penetration than a short pulse, the use of a long pulse is not recommended because

- A. the long ringing may interfere with nearby pulses
- B. the shorter pulse will provide better penetration
- C. a long pulse contains less energy than a shorter pulse
- D. a long pulse is recommended

Q.2-10 Backing material on a transducer is used to ____

- A. damp the pulse and absorb the sound from the back of the transducer
- B. decrease the thickness oscillations
- C. increase the radial mode oscillations
- D. increase the power of the transmitted pulse

- Q.2-11 Angle beam search units are used to
- inspect butt welds in thick-wall steel piping
 - produce shear waves through mode conversion
 - examine material volumes inaccessible to normal beams
 - all of the above

- Q.2-12 An angle beam produces a 45-degree shear wave in steel. What is the approximate incident angle? (velocity in steel = 0.125 in. / micro-sec, velocity in plastic = 0.105 in./microsec)
- 54.9 degrees
 - 19 degrees
 - 36.4 degrees
 - 45 degrees

- Q.2-13 In Figure 2.6, the aluminum rod being examined is 6 in. in diameter. What is the offset distance needed for a 45-degree refracted shear wave to be generated? (L-wave velocity in aluminum = $6.3 (10)^5$ cm/sec, T-wave velocity in aluminum = $3.1 (10)^5$ cm/sec, velocity in water = $1.5 (10)^5$ cm/sec)
- 0.513 cm
 - 1.026 in
 - 2.052 in
 - 1.505 cm

- Q.2-14 In Figure 2.6 and using the conditions of Q.2-13, what is the offset distance needed for a 45-degree refracted longitudinal wave to be generated?
- 0.395 in
 - 0.450 cm
 - 0.505 in
 - 1.026 cm

- Q.2-15 It is desired to detect flaws 1/4 in. or less from the entry surface using angle beam shear waves. The search unit must be selected with the choice between a narrow band and a broad band unit. Which should be chosen and why?
- the narrow band unit because it examines

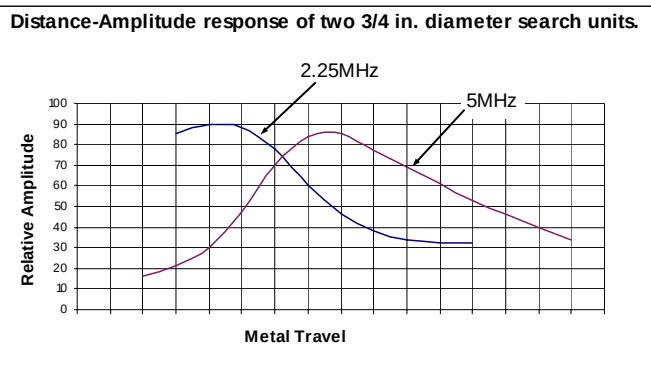
- only a narrow band of the material
- the broad band unit because the entire volume is examined with a long pulse
- the broad band unit because the near surface resolution is better
- the broad band unit because the lateral resolution is excellent

- Q.2-16 In an immersion test of commercially pure titanium plate ($V_L = 6.1 (10)^5$ cm/sec, $V_T = 3.12 (10)^5$ cm/sec), an echo pulse from an internal defect is observed 6.56 μ sec following the front surface echo. How deep is the reflector below the front surface?
- 2 cm
 - 4 cm
 - 1 cm
 - 2 in

- Q.2-17 A change in echo amplitude from 20 percent of full screen height (FSH) to 40 percent FSH is a change of :
- 20 dB
 - 6 dB
 - 14 dB
 - 50 percent in signal amplitude

- Q.2-18 In Figure 2.10, what is the rate of attenuation, expressed in dB/in., of the 5 MHz transducer as observed in the far field? The horizontal scale is 0.5 in. per division.
- 1.00 dB/in.
 - 2.22
 - 2.55
 - 3.25

Figure 2.10



Q.2-19 In Figure 2.10, what is the rate of attenuation of the 2.25 MHz transducer using the conditions of Q.2-18?

- A. 2.0 dB/in.
- B. 3.5
- C. 4.0
- D. 8.0

Q.2-20 What lens radius of curvature is needed in order to have a 2 cm dia., 5 MHz transducer focus in water at a distance of 4 cm from the lens face? ($V_{H_2O} = 1.49 (10)^5$ cm/sec, $V_{Lens} = 2.67(10)^5$ cm/sec)

- A. 1.77 cm
- B. 3.50 cm
- C. 3.17 in
- D. 2.23 in

Q.2-21 Two signals were compared in amplitude to each other. The second was found to be 14 dB less than the first. This change could have represented a change of

- A. 70% FSH to 14% FSH
- B. 100% FSH to 50%r FSTT
- C. 20% FSH to 100% FSH
- D. 100% FSH to 25% FSH

Q.2-22 A change of 16 dB on the attenuator corresponds to an amplitude ratio of :

- A. 6.3
- B. 5.2
- C. 7.4
- D. 9.5

Q.2-23 When checked against a previous calibration level, a search unit which is classified as highly damped is considerably more sensitive. A check of the RF waveform shows that the unit rings for at least three times the number of cycles previously achieved. What condition might explain this phenomenon?

- A. the search unit has been dropped and the facing material has been cracked
- B. the hacking material has separated from the crystal, thus decreasing the mechanical damping
- C. the housing has separated from the transducer and thinks it is a hell
- D. the coax connector is filled with water

Q.2-24 The sound beam emanating from a continuous wave sound source has two zones. These are called the _____

- A. Fresnel and Fraunhofer zones
- B. Fresnel and near fields
- C. Fraunhofer and far fields
- D. focused and unfocused cones

Chapter 3

Common Practices

Chapter 3

Common Practices

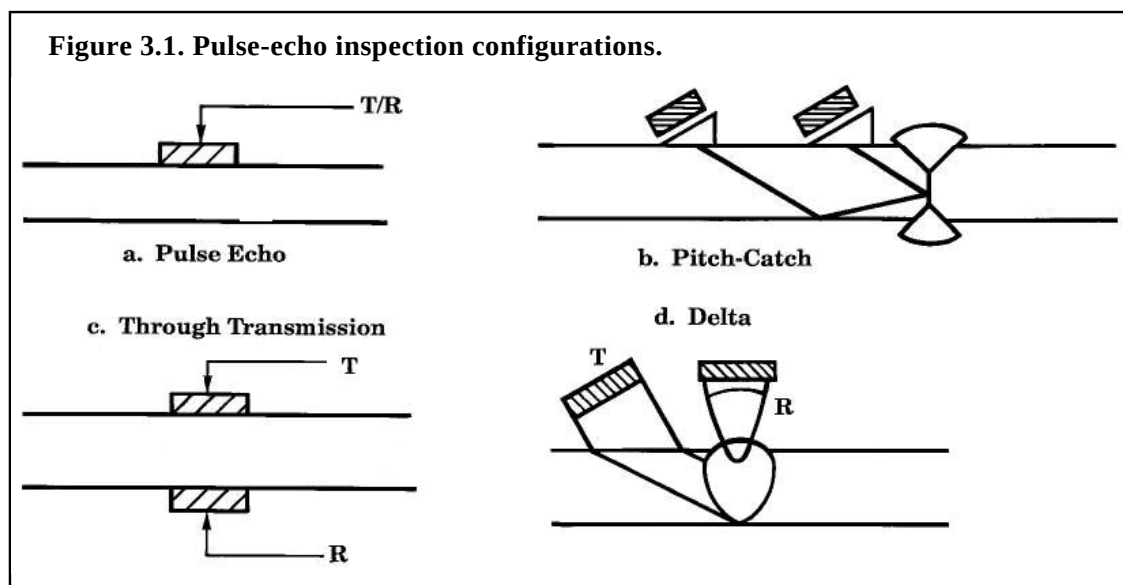
Approaches to Testing

Most ultrasonic inspection is done using the pulse-echo technique wherein an acoustic pulse, reflected from a local change in acoustic impedance, is detected by the original sending sound source. Received signals indicate the presence of discontinuities (internal or external) and their distances from the pulse-echo transducer, which are directly proportional to the time of echo-pulse arrival. For this situation, access to only one side of the test item is needed, which is a tremendous advantage over through-transmission in many applications. For maximum detection reliability, the sound wave should encounter a reflector at normal incidence to its major surface. If the receiving transducer is separated from the sending transducer, the configuration is called a pitch-catch. The interpretation of discontinuity location is determined using triangulation techniques. When the receiver is positioned along the propagation axis and across from the transmitter, the technique is called the through-transmission approach to ultrasonic testing.

Figure 3.1 shows these three modes of pulse-echo testing with typical inspection applications.

In the through-transmission technique, the sound beam travels through the test item and is received on the side opposite from the transmitter. Two transducers, a transmitter and a receiver, are necessary. The time represented on the screen is indicative of a single traverse through the material, with coupling and alignment being critical to the technique's successful application.

In some two-transducer pitch-catch techniques, both transducers are located on the same side of the material. The time between pulses corresponds to a single traverse of the sound from the transmitter to the reflector and then to the receiver. One approach uses a "tandem" pitch-catch arrangement, usually for the central region of thick materials. In this technique, the transmitter sends an angle beam to the midwall area of the material (often a double V weld root) and deflections from vertical planar surfaces are



received by one or more transducers located behind the transmitter. Another pitch-catch technique, found in immersion testing, uses a focused receiver and a broad-beam transmitter, arranged in the shape of a triangle (delta technique). This technique relies on re-radiated sound waves (mode conversion of shear energy to longitudinal energy) from internal reflectors, with background noise reduction through use of the focused receiver.

When sound is introduced into the material at an angle to the surface, angle beam testing is being done. When this angle is reduced to zero degrees it is called "straight" or "normal" beam examination and is used extensively on plate or other flat material. Laminations in plate are readily detected and sized with the straight beam technique. Although it is possible to transmit shear waves "straight" into materials, longitudinal waves are by far the most common wave mode used in these applications.

Sound beams can be refracted at the interfaces of two dissimilar media. The angles can range from just greater than 0 degrees to 91 degrees (corresponding to their limiting critical incident angle condition) if the second medium has the higher acoustic wave velocity. Shear wave angle beams are usually greater than 20 degrees (in order to avoid the presence of more than one mode being present within the material at the same time) and less than 80 degrees (in order to avoid the spurious generation of surface waves).

Angle beams (both shear and longitudinal) are often used in the examination of welds since critical flaws such as cracks, lack of fusion, inadequate penetration, and slag have dimensions in the through wall direction. Angle beams are used because they can achieve close-to-normal incidence for these reflectors with generally vertical surfaces. Other types of structures and configurations are examined using angle beams, particularly where access by straight - beams is unsatisfactory, e.g., irregularly shaped forgings, castings, and assemblies.

Surface (Rayleigh) waves are not as common as the longitudinal and shear waves, but are used

to great advantage in a limited number of applications *that* require an ability of the wave to follow the contours of irregularly shaped surfaces such as jet engine blades and vanes. Rayleigh waves extend from the surface to a depth of about one wavelength into the material and thus are only sensitive to surface or very near-surface flaws. They are very sensitive to surface conditions including the presence of residual coupling compounds as well as finger damping. Rayleigh waves are usually generated by mode conversion using angle beam search units designed to produce shear waves just beyond the second critical angle.

Two major modes of coupling ultrasound into test parts are used in UT: contact and immersion. The manual contact technique is the most common for large items which are difficult to handle, e.g., plate materials, structures, and pressure vessels. Both straight and angle beams are used. Coupling for the manual contact technique requires a medium with a higher viscosity than that of water and less than that of heavy greases. In mechanized (automated) testing, the couplant is often water that is made to flow between the transducer and the test piece. During manual tests, the operator provides the couplant repetitively during the examination.

Manual contact testing is very versatile since search units are easily exchanged as the needs arise, and a high degree of flexibility exists for angulation and changes in directions of inspection. Test items of many different configurations can be examined with little difficulty. One of the prime advantages of contact testing is its portability. UT instruments of briefcase size and weighing less than 20 pounds are readily available. With this type of instrument and contact techniques, UT is performed almost anywhere the inspector can go. Skilled operators can make evaluations on the spot and with a high degree of reliability.

Immersion testing uses a column of liquid as an intermediate medium for conducting sound waves to and from test parts. Immersion testing can be performed with the test item immersed in water (or some other appropriate liquid) or through use of various devices (bubblers and

squirters) that maintain a continuous water path between the transducer(s) and the test item. Most examinations are conducted using automatic scanning systems. The immersion technique has many advantages. Many sizes, shapes and styles of search units are available including flat, focused, round, rectangular, paintbrush, and arrays. Automated examination is easily accommodate. Surface finish is less troublesome since transducer wear does not take place. Various size and shape objects may he tested. Scanning can be faster and more thorough than manual scanning. Recording of position and flaw data is straight forward. Data precision is higher since higher frequency (and more fragile) transducers can he used.

Disadvantages include long setup time, maintenance of coupling liquids, preset scan/articulation plans reduce use of spontaneous positioning, high signal loss at test part-water interface, highly critical positioning/angulation problems, and system alignment in general.

Of all the advantages, perhaps the most important is the ability to use different search unit sizes and shapes in an automatic inspection mode. Beam focusing is commonly used to improve spatial resolution and increase sensitivity; however, scan times increase dramatically. Automated testing has many advantages, including increased scanning speed, reduced operator dependence, and adaptability to imaging and signal processing equipment.

Immersion tanks may be long and narrow (*for pipe and tubing inspection*) or short and deep (*for bulky forgings*). In general, tanks are equipped with *a* means for filling, draining, and filtering the water. The tank may contain test item manipulators (*for spinning pipe and rotating samples*) and a scanning bridge system (*for translating search units along rectilinear and/or polar coordinates*). Tank capacities range *from* one or two cubic feet to a few thousand cubic feet. Most tanks are equipped with one or more scanning bridges which travel on tracks the length of the tank and are under the control of *the operator or an* automatic test system. The bridge across the tank contains rails on which the search unit manipulator rides. Other equipment

carried on the bridge may include the ultrasonic instrument, a C-scan or other recorder, and signal processing equipment needed to extract information from the ultrasonic signals. Figure 3.2 shows an example of a typical tank configuration used for inspection of smaller items.

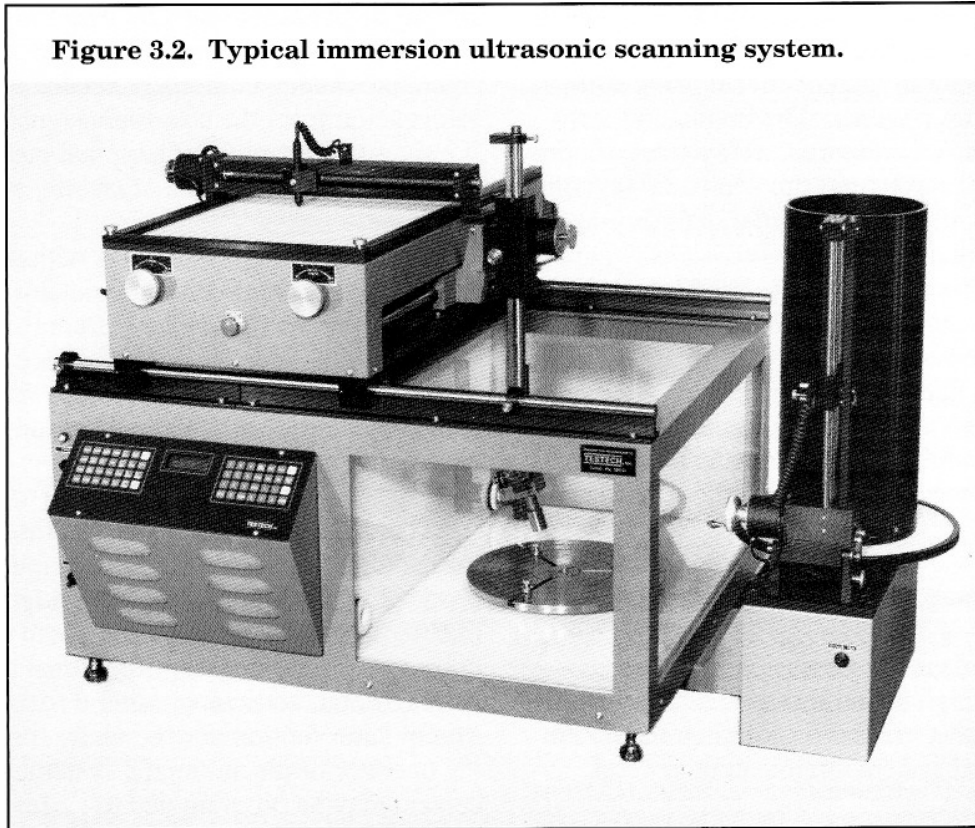
In scanning fiat test objects with a longitudinal beam, the search unit manipulator traverses the test item in a raster-like pattern (traverse-index-traverse-index-.....). The recorder, "enabled" using the gating circuits, records the data in synchronism with the position of the search unit manipulator.

There are several types of manipulators used for handling test parts. These manipulators shift or rotate the test item under the bridge in such a manner that the search unit may scan the required specimen surface. Rotational axes may he horizontal, vertical, or other desired angles. Manipulator motion may he under the control of the operator or the automatic system. Control Centers may be programmed to perform very basic scan patterns or, in the case of some computer-based systems, very complex operations. Most scans are preprogrammed and thus are not changed readily.

It is imperative that the search unit be in the desired position at all times so that the sound beam is interrogating the intended test area. This is accomplished by a positioner attached to the end of the search tube used to "point" the search unit in the desired direction. Thus the search unit has several degrees of positional freedom (X, Y, Z, θ , ϕ)

It is not always feasible to immerse a test object in a tank for UT testing. Limits are imposed by the size and shape *of* the test object as well as by the capacity of the tank. To circumvent these problems, scanning systems are often provided with squirters or water columns. While differing slightly in design, each of these serves the same purpose to establish a column of water between the search unit and the test item through which the sound beam will pass. Squirters employ a nozzle which squirts a stream of water at the test piece. The search unit, located inside and coaxially with the nozzle.

Figure 3.2. Typical immersion ultrasonic scanning system.



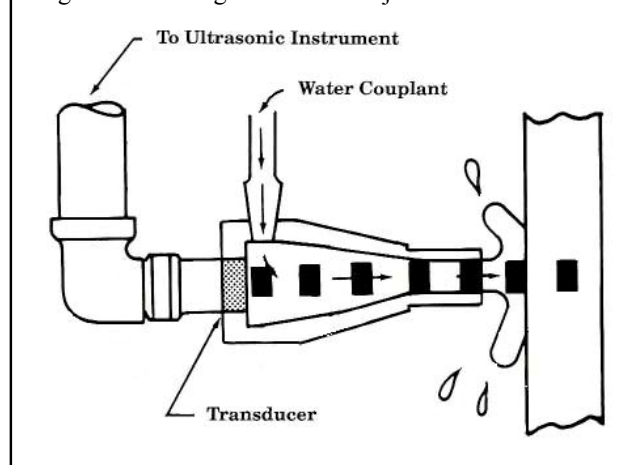
emits a sound beam axially through the stream, Figure 3.3 shows a conceptual drawing of an ultrasonic water jet (squirter).

If the nozzle is designed properly and the water flow parameters are set correctly, there are no bubbles at the interface of the water and the test piece and sound can be transmitted into the piece. The sound beam impinging on a test part is restricted in cross-sectional size by the stream of water which acts as a wave-guide and collimator. Both the squirter and the bubbler (water column) can be used with pulse-echo or through-transmission techniques and can take advantage of beam focusing. If the free stream of the squirter is long, the deflection due to gravity may have to be considered in the scanning plan.

It is often desirable to keep a test item relatively dry while performing ultrasonic examinations. One way of doing this and yet maintain many of the advantages of immersion testing is to use wheel transducers. The wheels used for UT testing are similar to automotive tires in that they are largely hollow and there is a flexible "tread" in contact with the test item. In the UT

wheel, the search unit is mounted on a gimbal manipulator inside the tire and the tire is filled with a liquid - usually water. The search unit is aimed through the tread (a thin elastomeric membrane such as polyurethane). The gimbal mounting permits the incident sound beam to be oriented so that it produces either shear or longitudinal waves (or other modes) in the test part as if immersion testing were taking place.

Figure 3.3. Diagram of a water jet for ultrasonic tests



Because the tire is flexible and conforms to the surface, little external couplant is needed. At times, however, a small spray of water or alcohol is introduced just ahead of the wheel to exclude the possibility of small amounts of air becoming trapped at the wheel's contact surface. This thin layer of liquid evaporates rapidly without damage to the test item. Although wheels are somewhat limited as to the shapes of materials they can examine, they are useful on large, reasonably flat surfaces. More than one wheel can be used at the same time, e.g., tandem configurations are, - possible. They are useful in high temperature applications (where the liquid is continuously cooled) and sets of transducers can be placed within a single wheel. A major problem is the elimination of internal echoes from structural members within the liquid chamber. These echo problems are usually eliminated by careful design incorporating the empirical placement of baffles and absorbers.

In both manual and automatic scanning, the pattern of scanning is important. If too many scan traverses are made the part will be over tested, with time and money being lost. On the other hand, if the coverage of the scans is insufficient, sections of the part will not be examined and defects may be missed. Therefore, time dedicated to developing a scanning plan is seldom wasted. In developing the plan, which lays out the patterns of search unit manipulation, it is necessary to consider applicable codes, standards, and specifications as well as making an engineering evaluation of the potential locations, orientations, sizes, and types of flaws expected in the part. After these criteria have been developed, sound beam modes, angles, beam spread, and attenuation must all be considered to assure that all of the material is interrogated in the desired direction(s). This information is used to establish scan lengths, direction, overlap, index increments, and electronic gate settings.

Measuring System Performance

UT calibration is the practice of adjusting the gain, sweep, and range, and of assessing the

impact that other parameters of the instrument and the test configuration may have on the reliable interpretation of ultrasonic signal echoes. Gain settings are normally established by adjusting the vertical height of an echo signal, as seen on the CRT, to a predetermined level. The level may be required by specification and based on echo responses from specific standard reflectors in material similar to that which will be tested. Sweep distance of the CRT is established in terms of equivalent "sound path," where the sound path is the distance in the material to be tested from the sound entry point to the reflector.

It is important to establish these parameters. Gain is established so that comparisons of the reference level can be made to an echo of interest in order to decide whether the echo is of any consequence and, if so, then to aid in the determination of the size of the reflector.⁶ Sweep distance is established so that the location of the reflector can be determined.

Horizontal linearity is a measure of the uniformity of the sweep speed of the instrument. The instrument must be within the linear dynamic ranges of the sweep amplifiers and associated circuitry in order for electron beam position to be directly proportional to the time elapsed from the start of the sweep. It may be checked using multiple back-echoes from a flat plate of a convenient thickness, i.e., 1 inch. With the sweep set to display multiple back-echoes, the spacing between pulses should be equal. The instrument should be recalibrated if the sweep linearity is not within the specified tolerance. Vertical linearity implies that the height of the pulse displayed on the A-scan is directly proportional to the acoustic pulse received by the transducer. For example, if the echo increases by 50 percent, the indicated amplitude on the CRT should also change by 50 percent. This variable may be checked by establishing an echo signal on the screen, changing the vertical amplifier gain in set increments, and measuring the corresponding changes in A-scan response. An alternate check uses a pair of echoes with amplitudes in the ratio

⁶It is important to recognize that the use of amplitude to size a reflector is subject to large, uncontrolled errors and must be approached with caution.

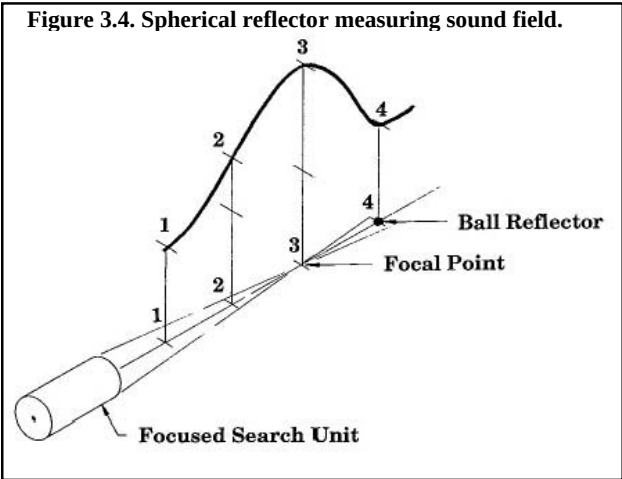
of 2:1. Changes in gain should not affect the 2:1 ratio, regardless of the amplifier's settings.

It is of note that when electronic DAC units are used in an ultrasonic system, the vertical amplifier's displayed output is purposefully made to be nonlinear. The nature of the nonlinearity is adjusted to compensate for the estimated (or measured) variation in the test material/ inspection system's aggregate decay in signal strength as a function of distance (time) from the sending transducer.

Reference Reflectors

There are several reflector types commonly used as a basis for establishing system performance and sensitivity. Included among them are spheres and flat-bottom holes (FBH), notches, side-drilled holes (SDH), and other special purpose or designs. Table 3.1 summarizes these reflectors and their advantages and limitations.

Spherical reflectors are used most often in immersion testing for assessing transducer sound fields as shown in Figure 3.4. Spheres provide excellent repeatability because of their omnidirectional sound wave response. The effective reflectance from a sphere is much smaller **than** that received from a flat reflector of the same diameter due to its spherical directivity pattern. Most of the reflected energy does not return to the search unit. Spheres of any material can be used; however, steel ball bearings are the norm since these are reasonably priced, extremely



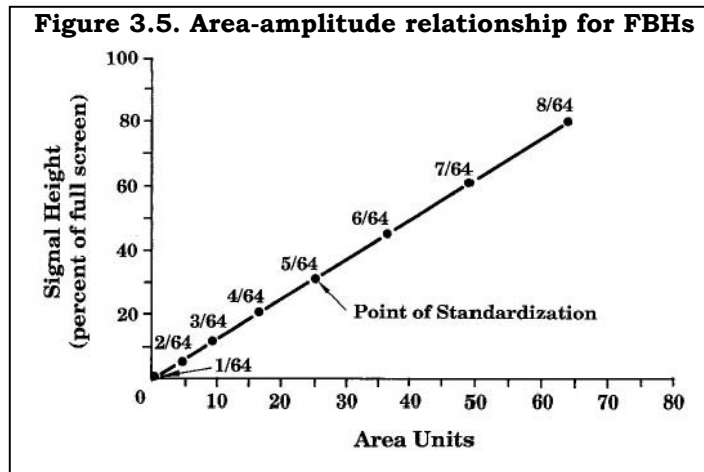
precise as to size and surface finish, and available in many sizes.

Flat reflectors are used as calibration standards in both immersion and contact testing. They are usually flat-bottom drilled holes of the desired diameters and depths. All **flat** reflectors have the inherent weakness that they require careful sound beam-reflector axis alignment. Deviations of little more than a few degrees will lead to significantly reduced echoes and become unacceptable for calibration. However, for flaws of cross-section less than the beam width and with a perpendicular alignment, the signal amplitude is proportional to the area of the reflector as shown in Figure 3.5. Generally, if a flaw echo amplitude is equal to the amplitude of the calibration reflector, it is assumed that the flaw is at least as large as the calibration reflector.

Table 3.1. Reference Reflectors Used in Ultrasonic Testing

Type	Characteristics	Uses
Solid Sphere	Omni-directional	Transducer sound field assessment
Notches	Flat, corner	Simulates near-surface cracks
Flat-Bottom Hole (FBH)	Disc reflector	Reference gain
Side-Drilled Hole (SDH)	Cylindrical symmetry	Distance DAC calibration
Special	Custom reflectivity	Simulate natural flaw conditions

Notches are frequently used to assess the detectability of surface-breaking flaws such as cracks, as well as for instrument calibration. Notches of several shapes are used and can either be of a rectangular or "Vee" cross section. Notches may be



overall sensitivity of shear wave testing schemes. After the sweep distance is set, signals from each reflector are maximized (by maneuvering the search unit) and the results are recorded on the CRT screen using erasable markers. The peak signals from each reflector are then connected by a smooth line and it is this line that is called the distance-amplitude correction (MAC) curve.

Calibration

made with milling cutters (end mills), circular saws; or straight saws. End-mill (or EDM) notches may be made with highly variable length and depth dimensions. Circular saw cuts are limited in length and depth by the saw diameter and the configuration of the device holding the saw. Even though it is somewhat more difficult to achieve a desired length to depth ratio with the circular saw, these notches are used frequently because of their resemblance to fatigue cracks, e.g., shape and surface finish. Notches may be produced perpendicular to the surface or at other angles as dictated by the test configuration. On piping, they may be located on the inside diameter and/or the outside diameter and aligned either in the longitudinal or transverse directions.

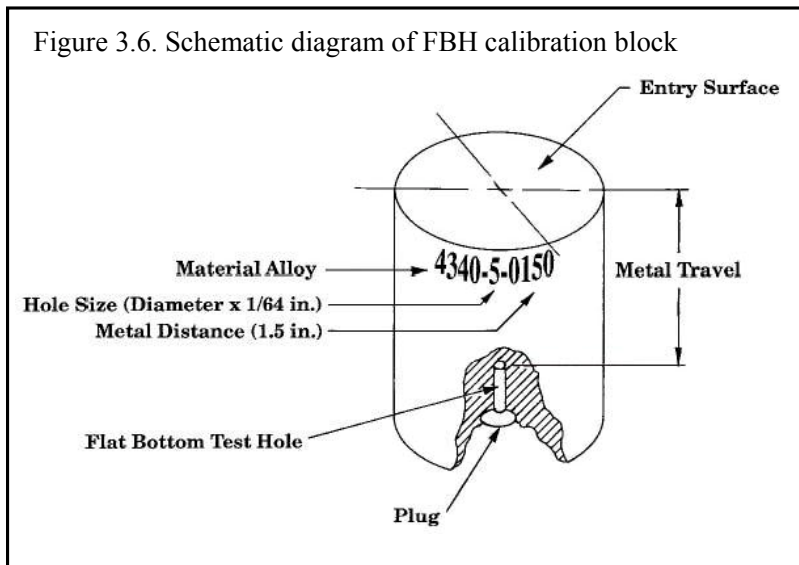
Side-drilled holes are placed in calibration blocks so that the axis of the hole is parallel to the entry surface. The sound beam impinges on the hole, normal to its major axis. Such a reflector provides very repeatable calibrations, may be placed at any desired distance from the entry surface and may be used for both longitudinal waves and a multitude of shear wave angles. It is essential that the hole surface be smooth, thus reaming to the final diameter is often the final step in preparing such holes.

Used in sets with differing distances from the surface and different diameters, side-drilled holes are frequently used for developing distance-amplitude correction curves and for setting

The setting of basic instrument controls is expedited by the use of several standard sets of blocks containing precision reflectors arranged to feature a specific characteristic of the inspection systems. For example, area-amplitude blocks contain flat-bottom holes of differing diameters, all at the same distance from the sound entry surface. The block material is normally similar to that of the test material. In the ALCOA (Aluminum Company of America) "A" series of blocks, each hole is placed in a separate cylinder 2 in. in diameter. Other blocks, intended for the same purpose of establishing the correlation of signal amplitude with the area of the reflector, may contain a number of holes in the same block, usually a plate. Hole sizes increase in sixty-fourths of an inch and are designated by that value. For example, a 1/16 in. (4/64 in.) hole is a #4 hole. Area amplitude blocks are used to establish the area/amplitude response curve and the sensitivity-of the UT system. Maximum signals are obtained from each of the holes of interest and the signal amplitude is recorded. These values may be compared to echoes from the same metal path and reflector sizes estimated for the test item. Figure 3.6 shows a cross-sectional diagram of a block composed of 4340 steel, with a FBH size of 5/64 in. (#5 hole) and a travel distance of 1.5 in.

Distance-amplitude blocks (B blocks) differ from area-amplitude blocks in that a single diameter, flat-bottom hole is placed at incrementally increasing depths from very near the entry surface to a desired maximum depth. Sets of

Figure 3.6. Schematic diagram of FBH calibration block



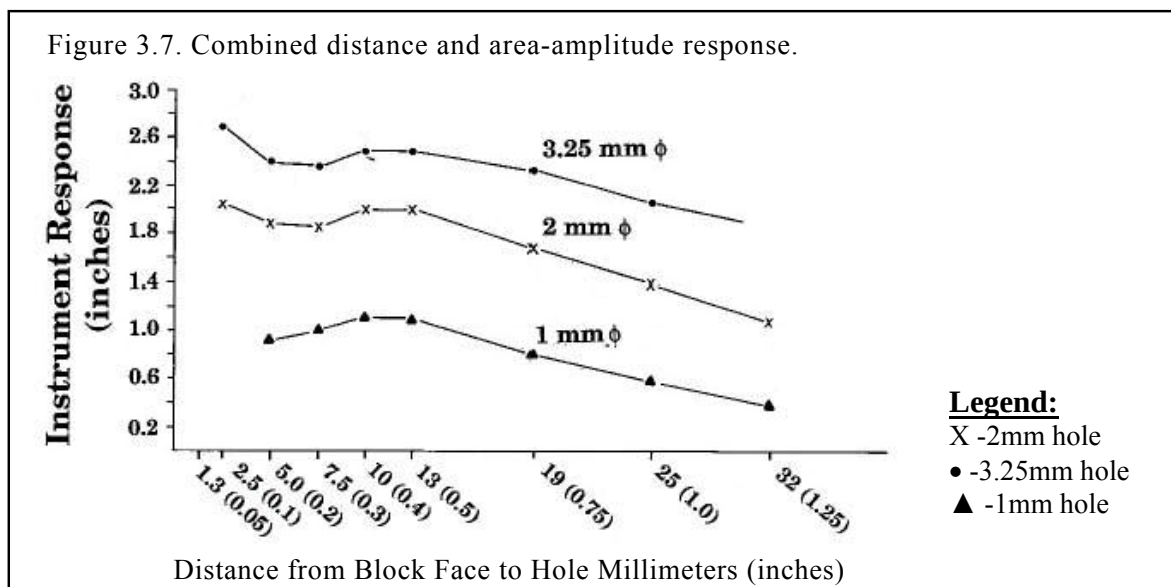
There are numerous blocks commercially available that are used in calibrating UT instruments, both for sweep distance (sound path) and for sensitivity (gain) as well as depth resolution. Included in this group are the IIW (International Institute of Welding), DSC (distance and sensitivity calibration), DC (distance calibration block), SC (sensitivity calibration block), and the AWS RC (Resolution Calibration Block).

Other special blocks are often required in response to specification and Code requirements based on the construction of the blocks, using materials of the same nature as those to be inspected. Included are the ASME weld inspection blocks such as the SDH for angle beam calibration, curved blocks for piping/nozzles simulation, and nozzle drop-outs (circular blanks cut from vessel plates) for custom nuclear in-service inspection applications. Finally, attempts are ongoing to develop schemes for making reflectors which directly behave as cracks and to generate actual cracks, particularly inter granular stress corrosion cracks. Table 3.2 summarizes many of these blocks and their intended uses.

blocks are available in different materials and with diameters ranging from Number 1 to Number 16 and larger. Distance-amplitude blocks are used to establish the distance/amplitude response characteristic of the UT system in the test material; the measured response includes the effects of attenuation due to beam slit-cad and scattering and/or absorption. With this curve established, the operator can compensate for the effects of attenuation with distance. Distance-amplitude blocks are useful in setting instrument sensitivity (gain) and if present the electronic distance-amplitude correction circuits. Figure 3.7 shows a composite set of DAC and area-amplitude calibration curves taken from a block containing three different hole sizes (1 mm, 2 mm, and 3.25 mm), measured at distances ranging from 2.5 mm to 32 mm.

One of the best known calibration blocks is the IIW block shown in Figure 3.8. This block is used primarily for measuring the refracted angle

Figure 3.7. Combined distance and area-amplitude response.



of angle beam search units, setting the metal path, and establishing the sensitivity for weld inspection. To measure the refracted angle, the sound beam exit point is determined on the 4 in. radius. The angle is then determined by maximizing the signal from the large side-drilled hole and reading the exit-point position on the engraved scale.

Various reflectors are provided in modified IIW blocks to provide the capability to set the sweep distance. These include grooves and notches at various locations which yield echoes at precisely known distances. The block may also be used for setting distances for normal (straight beam) search units using the 1 in. thickness of the block. Distance resolution may also be checked on the notches adjacent to the 4 in. radius surface. Because different manufacturers provide variations in the configuration of the block, other specific uses may be devised.

The distance calibration (DC) block is specifically designed for setting up the sweep distance for both normal and angle beam testing for either longitudinal, shear, or surface waves. For straight beam calibration, the search unit is placed on the 1 in. or 1/2 in. thick portion and the sweep distance adjusted.

For angle beam calibration, the search unit is placed on the flat surface at the center of the cylindrical surfaces. Beam direction is in a plane normal to the cylinder axis. When the beam is directed in such a manner, echoes should occur at 1, 2, or 3 in. intervals. With a surface wave search unit at the centerline, a surface wave may be calibrated for distance by observing the echoes from the 1 and 2 in. radii and adjusting the controls accordingly.

A miniature multipurpose block is shown in Figure 3.9. The block is 1 in. thick and has a 1/16 in. diameter side-drilled hole for sensitivity settings and angle determinations. For straight beam calibration, the block provides back reflection and multipliers of 1 in. For angle beams, the search unit is placed on the flat surface with the beam directed toward either of the curved surfaces. If toward the 1 in. radius, echoes will be received at 1 in., 4 in., and 7 in. intervals. If toward the 2 in. radius, the intervals will be 2 in., 5 in., and 8 in. Refracted angles are measured by locating the exit point using either of the curved surfaces. The response from the side-drilled hole is maximized and the angle read from the engraved scales. Single point (zone) sensitivity can be established by maximizing the signal from the SDH.

Table 3.2. Calibration Block Usage

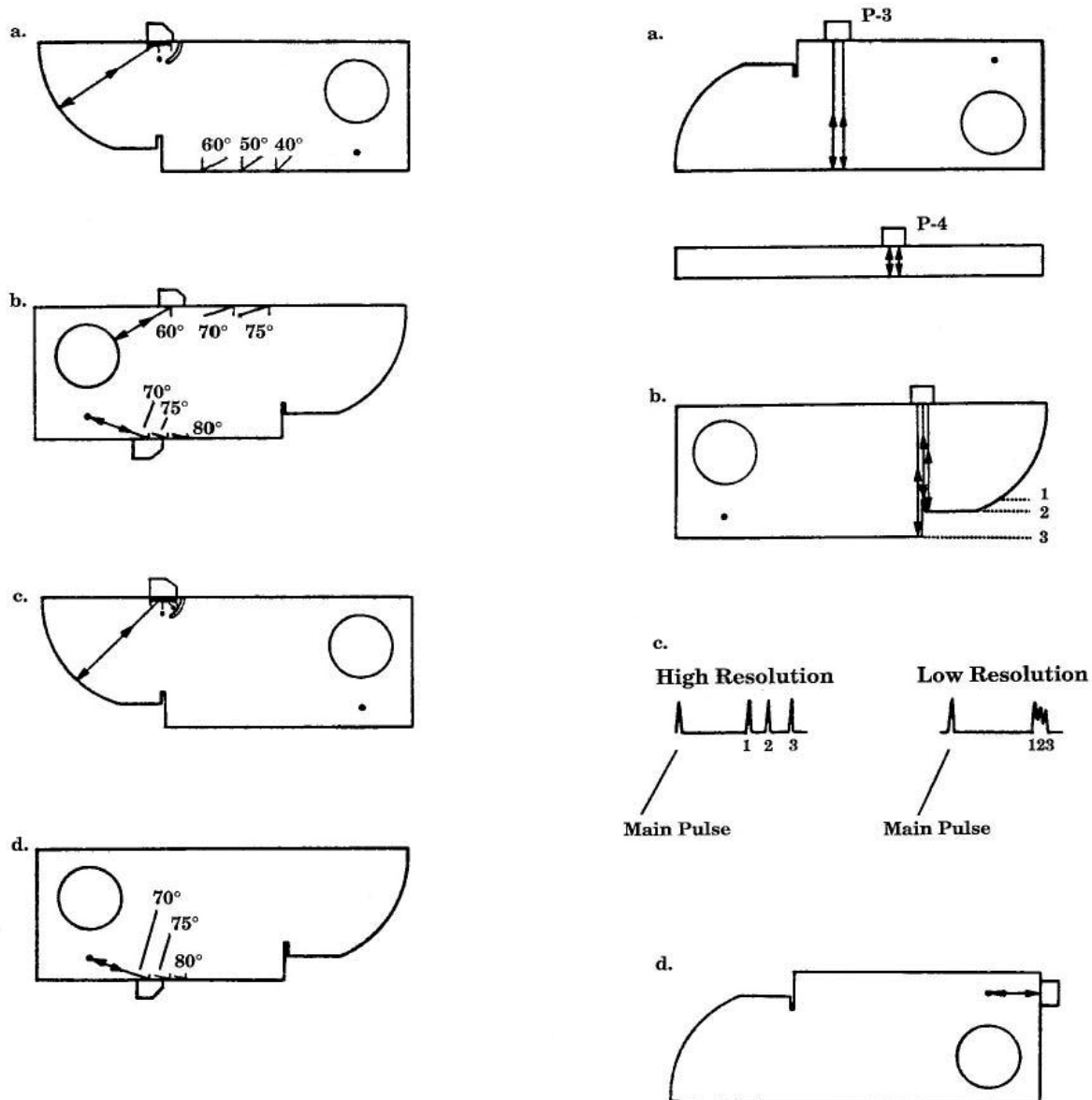
Characteristic	Block Designation							
	IIW	DSC	ASMF (SDH)	DC	SC	B	A	AWS (RC)
Sweep Range	X/0	X/0	X/0	X/0	---	0	0	---
Sensitivity	X/0	X/0	X/0	---	X	0	0	---
Exit Point	X	X		X				
Exit Angle	X	X			X		---	---
DAC			X/0			0		
Depth Resolution	0	---	---	---	---	0 ²	---	X
Curvature compensation	---	---	X ¹	---	---	---	---	---

Legend:

- x -- Shear Wave
- 0 -- Longitudinal Wave
- 1 -- Set of Curved Blocks Used
- 2 -- Near Surface Only

Distance-amplitude correction curves can be developed for any number of test part thicknesses using the SDH block shown in figure 3.10 by placing the angle beam transducer on surfaces which change the sound path distance

Figure 3.8. IIW block for transducer and system calibration.



a series of peaked responses can be recorded and plotted on the CRT screen in the form of a IAC over the range of distances of interest to inspection.

An example of a special block designed to compensate for convex surface effects is shown in Figure 3.1 1. Included are the geometrical features with tolerances needed in the construe-titan of typical calibration blocks.

A more suitable, but expensive, approach to the testing of complex parts involves the use of

sacrificial samples into which are placed wave reflectors such as FBHs, SDHs, and notches. (See Figure 3.12.)

Reference blocks based upon imbedded natural reflectors such as cracks by diffusion bonding, although useful for the purposes of establishing a baseline for self-teaching adaptive learning networks and related technologies, are very difficult to duplicate and suffer from an inability of developing an exact correlation with naturally occurring flaws. ?f concern is the inability to duplicate test samples on a wide-

Figure 3.9. Miniature angle beam calibration block.

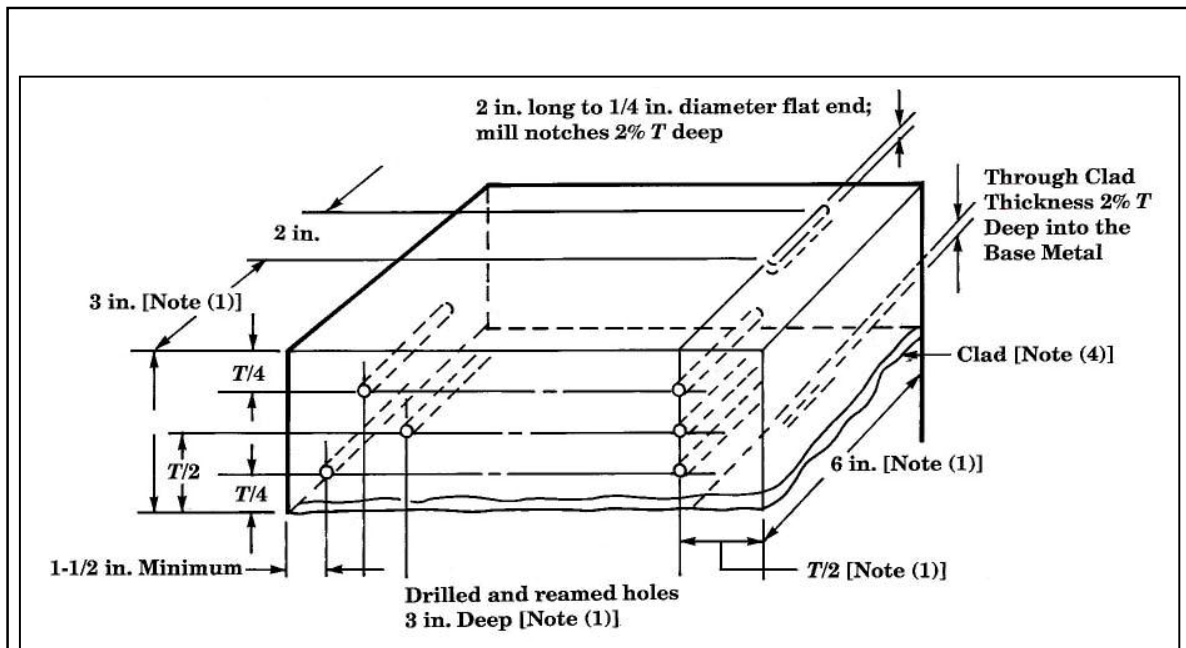
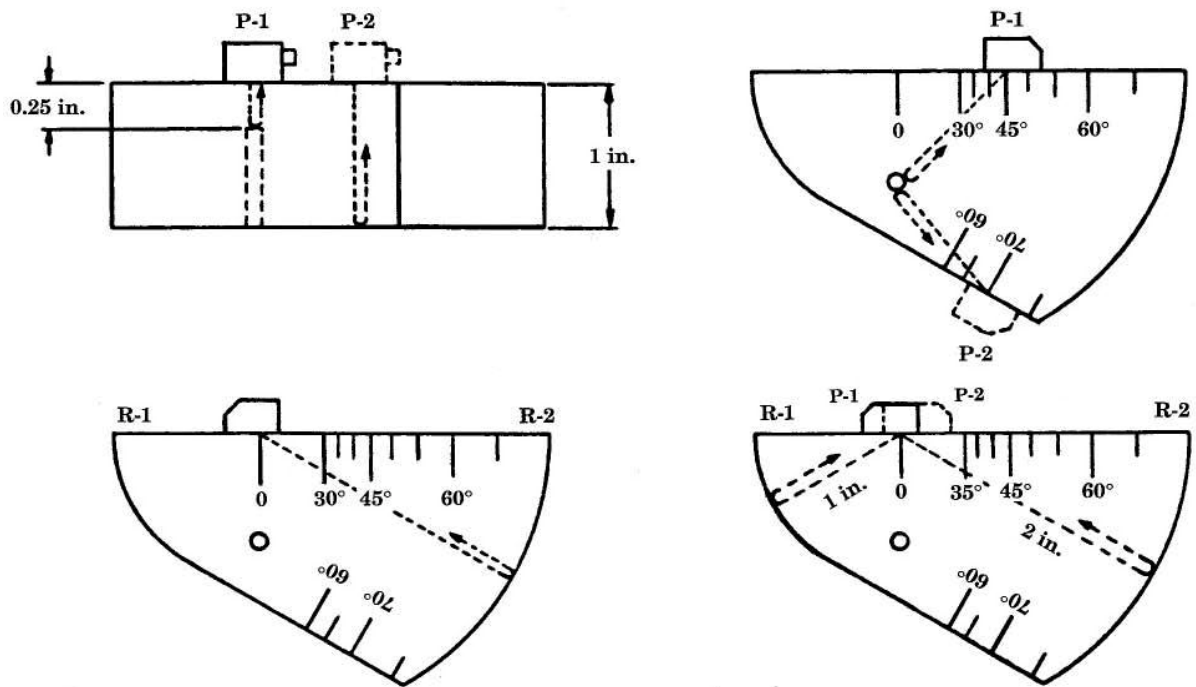
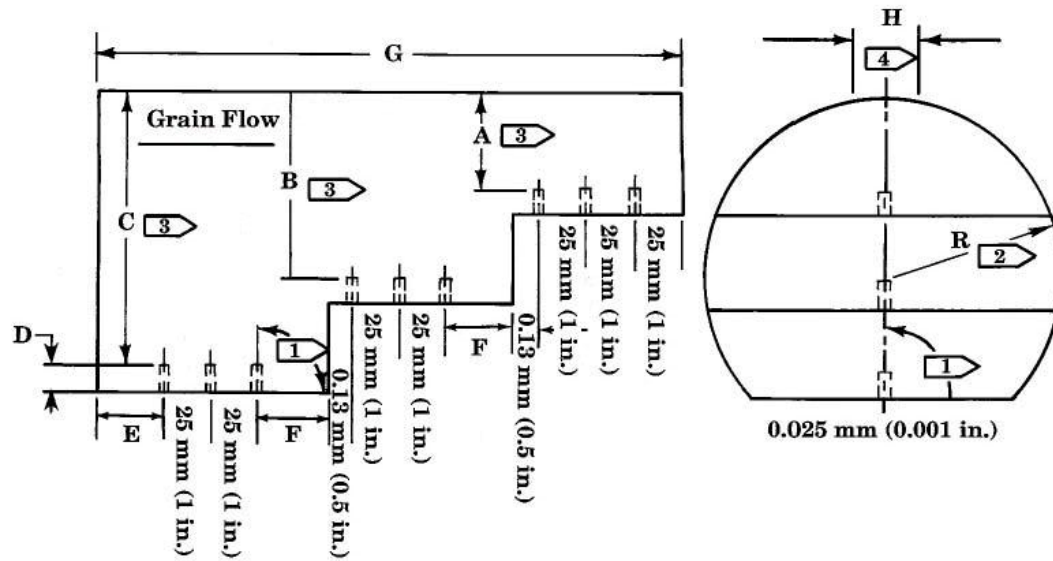


Figure 3.10. Calibration block for DAC development using angle beams.

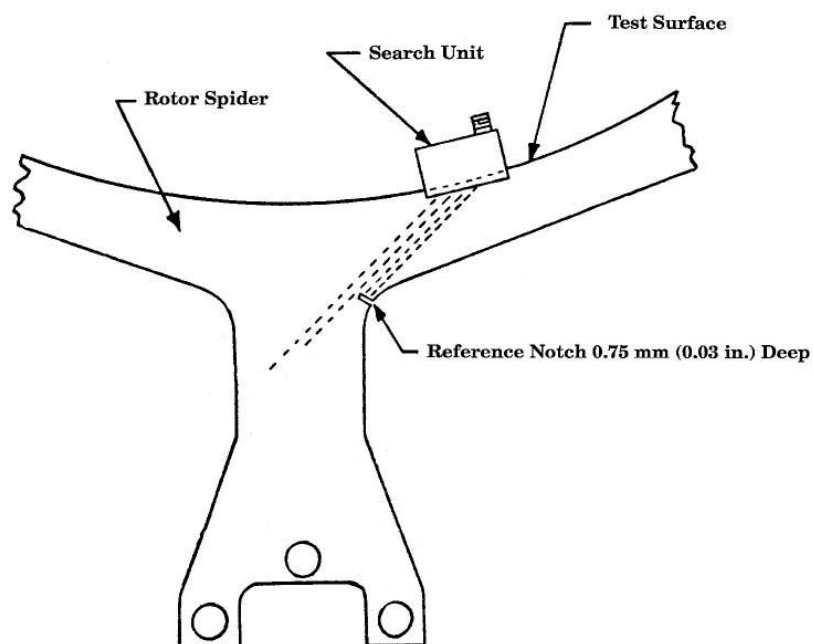
Figure 3.11. Convex surface reference block.



LEGEND

- 1 90 degrees ± 30 minutes typical
- 2 Tolerance: ± 0.025 in.
- 3 Tolerance: ± 0.01 in.
- 4 100 RHR maximum top surface

Figure 3.12. Use of reflectors in sacrificial (simulated) test parts.



spread production basis; once destructive correlations are carried out, remaking the same con-figuration is questionable. Even when such reflectors can be duplicated to some extent, the natural variability of flaws found in nature still tends to make this approach to reference standards highly questionable.

In all cases, the block materials used for calibration purposes must be similar to the test materials to which the techniques will be applied. The concept of transfer functions has been used with limited success in most critical calibration settings.

Chapter 3 Review Questions

Q.3-1 Calibration is the term used to _____.

- A. describe the means to measure the diameter of a shaft
- B. set up the test item for examination in accordance with rules established by the NIST (formerly the NBS)
- C. describe the means to establish the working characteristics of a search unit
- D. describe the process of establishing the gain level and the sweep distance of the UT instrument

Q.3-2 An area-amplitude block has the designation 4340-4-0500. This indicates that it is

- A. an aluminum block with a #3 hole at a depth of 5 in.
- B. a steel block with a 1 1/16 in. hole at a depth of 5 in.
- C. a steel block with a #5 hole at a depth of 4 in.
- D. a Titanium block with a #4 hole at a depth of 5 in.

Q.3-3 The term "sweep distance" is used to describe

- A. how fast the sound is able pass through the material
- B. the equivalent sound beam path displayed on the CRT in terms of unit distances in the test material
- C. the velocity with which the search unit is moved across the material
- D. how electrical energy passes from the transducer to material being tested

Q.3-4 A calibrated CRT screen is necessary for

- A. measurement of signal amplitudes to determine distance to the reflectors
- B. measurement of electric currents generated by the piezoelectric crystal
- C. measurement of distances from the beginning to the end of the scan path
- D. measurement of distance along the sound path to establish thickness or reflector location

Q.3-5 A reflector signal was found to be 6 dB less than that from the calibration reflector at the same sound path. The calibration reflector was a No. 8 FBH. What can be said about the unknown reflector?

- A. it is 4/64 in. diameter
- B. it is 8/64 in. diameter
- C. it is probably 8/64 in. diameter or larger
- D. it is an unknown size

Q.3-6 In Figure 3.7, the response from the 3.25 mm FBH at a depth of 25 mm, is above that detected from the 1 mm FBH by

- A. 24.0 dB
- B. 18.2 dB
- C. 12.0 dB
- D. 10.8 dB

Q.3-7 The half-angle beam spread of the reflected wave front from a #8 FBH in an aluminum "A" block being immersion tested using a 25 MHz transducer is _____. $V_L = 1.5$ (Water); $V_{T\text{ Al}} = 6.3$; $V_{L\text{ Al}} = 3.1$; ...all times $(10)^5$ cm/sec.

- A. 1.30 degrees
- B. 5.47 degrees
- C. 22.77 degrees
- D. 48.50 degrees

Q.3-8 A DAC Curve is to be established using the SDHs in the block as shown in Figure 3.10. Three points have been established; 1/8, 2/8, and 3/8 nodes from 1/4, 1/2, 3/4 T SDHs. What would be the next point?

- A. 4/8 node
- B. 5/8 node
- C. 6/8 node
- D. 8/8 node

Q.3-9 Which of the following is an advantage of side-drilled hole reflectors for calibration?

- A. they can be placed at essentially any distance from the entry surface
- B. the surface of the hole is rough, providing a strong, specular reflection
- C. the hole depth is limited to 3 times the diameter
- D. the hole diameter can be used directly and easily to measure the size of an unknown reflector

Q.3-10 When measuring the angle on an angle beam search unit using an IIW block, two signals are noted. The first measures at an angle of 49 degrees and the second peaks at an angle that is estimated to be 25 degrees. Plastic longitudinal velocity = 2.76 mm/microsec; steel shear velocity = 3.23 mm/microsec; longitudinal velocity = 5.85 mm/microsec. Identify the signals.

- A. first is shear, second is longitudinal
- B. first is longitudinal, second is surface
- C. first is longitudinal, second is Love wave
- D. first is longitudinal, second is shear

Q.3-11 When using a focused, straight beam search unit for lamination scanning in an immersion test of a steel plate, a change in water path of 0.2 in. will result in the focal point moving in the steel a distance of

- A. 0.2 in.
- B. 0.2 rem
- C. 0.05 in.
- D. 0.8 in.

Q.3-12 A search unit with a focal length in water of 4 in. is used. A steel plate, 8 in. thick, velocity = 0.230 in./microsec., is placed at a water path of 2 in. from the search unit. At what depth is the focal point in the steel?

- A. 1.0 in.
- B. 2.0 in
- C. 0.5 in
- D. 0.8 in

Q.3-13 During an examination, an indication of 25% FSH is detected and maximized on the CRT. For better analysis the gain is increased by 12 dB and the indication increases to 88% FSH. What value should have been reached and what is the apparent problem?

- A. 50% FSH and the screen is nonlinear
- B. 75% FSH and there is no problem
- C. 100% FSH and the sweep speed is nonlinear
- D. 100% FSH and the screen is nonlinear

Q.3-14 The difference between through-transmission and pitch-catch techniques is _____

- A. that the transducers in through-transmission face each other, while in pitch-catch the transducers are often side-by-side in the same housing
- B. that the transducers in through-transmission

are side-by-side, while in pitch-catch the transducers are facing each other

- C. that the transducers in through-transmission are always angle beam
- D. that in through-transmission the depth of the flaw is easily determined

Q.3-15 In the tandem technique a signal is received from the test material. The reflector may be located

- A. at the front surface
- B. at the back surface
- C. somewhere near midwall
- D. by any of the above, depending on the material thickness, the refracted angle, the distance between search units, and the distance between transducer and the reflector

Q.3-16 In a tandem 70 degree pitch-catch shear wave arrangement, the plate being inspected is 2 in. thick and the region of interest is midway between top and bottom surfaces. How far behind the transmitter should the receiving transducer be located?

- A. 0.68 in.
- B. 1.88 in.
- C. 4.00 in.
- D. 5.50 in.

Q.3-17 Angle beam search units are frequently used in weld testing. One reason for this is that _____.

- A. the angle beam is more sensitive to slag and porosity
- B. the angle beam is more sensitive to inadequate penetration and cracks -
- C. the angle beam does not attenuate as it traverses the material
- D. the angle beam provides multiple back-surface echoes for thickness testing

Q.3-18 An automated examination of a large cylinder is to be performed using a focused search unit (focal point = 0.050 in. diameter, focal length = 2 in. and crystal diameter = 0.500 in.). To insure 10 percent overlap between scans, of the following, what increment should be used?

- A. 0.005 in.
- B. 0.495 in.
- C. 0.040 in.
- D. 0.0495 in.

Q.3-19 While performing a straight-beam, immersion test, an indication is noted lying midwall. What immediate action should the operator take?

- A. report it to his/her supervisor
- B. check to insure that the search unit to part distance is correct
- C. replace the component within another identical one to see if the same indication exists in the second unit
- D. check to ensure the refracted angle is 45 degrees

Q.3-20 The reflected pulse reaching the immersion transducer from the back surface of a 4.5-in. aluminum plate standing in a tank of water is equal to of the energy pulse which was transmitted from the transducer. ($Z_{Al} = 17$, $Z_{water} = 1.5$)

- A. 6.22 percent
- B. 70.2 percent
- C. 50.7 percent
- D. 14.7 percent

Q.3-21 A test on a thick part will be performed using a focused search unit with a 0.50 in. long focal zone as determined by the 3 dB down points. To insure complete coverage at uniform sensitivity, the operator should take which of the following actions?

- A. set the focal zone midway in the part and proceed with the examination
- B. set the focal spot at the front surface such that the divergent beam will attain maximum coverage
- C. set the focal zone at the back surface because that is the most critical area
- D. perform multiple examinations with the water path decreased by no more than 0.5 in. per examination

Q.3-22 A pair of squirters each with a 9 in. water stream are used in the examination of a large panel in the through-transmission mode. The search units are arranged in a horizontal position. It is desired to locate discontinuities within 0.010 in. of their true position. The analyst should take which of the following actions?

- A. assume that the coordinates given by the scanning system are correct and use those

values for the coordinates

- B. determine the curve of the water stream due to the influence of gravity and adjust the coordinate values to compensate for the deflection
- C. overlay the test record on the part and mark the reflector locations
- D. precisely measure from the index point on the panel to the indicated location and mark the part

Q.3-23 An air-filled #3 FBH. 0.5 in. into the bottom of a 4.5 in. aluminum block, will return to the 0.75 in. dia. sending immersion transducer an echo signal equal to of the initial pulse. Assume no attenuation due to beam divergence or other causes.

- A. 2.20 percent
- B. 1.10 percent
- C. 0.036 percent
- D. 0.05 percent

Q.3-24 In preparing a scanning plan (the set of directions describing the performance of an ultrasonic examination), which of the following parameters should be considered. as a minimum?

- A. sound beam diameter, refracted angle, beam direction, gate settings, starting point for the first scan, number of scans
- B. sound beam diameter, refracted angle, operator's name, gate settings, starting point, number of scans
- C. sound beam diameter, refracted angle, beam direction, expected flaws, instrument serial number
- D. sound beam far field length, refracted angle, beam direction, gate settings, starting point, number of scans

Q.3-25 A 3 in. thick flat plate of Polystyrene during immersion testing exhibits an echo from the back surface of the plate that is _____ of that received from the front surface. (Both sides immersed in water, $Z_{Poly} = 2.7$, $Z_{water} = 1.5$)

- A. 8.4 percent
- B. 84.00 percent
- C. 8.16 percent
- D. 6.88 percent

Q.3-26 A major problem in the use of search unit wheels is

- A. insufficient traction leading to skidding and had wrecks
- B. elimination of troublesome internal echoes
- C. installing adequate brakes
- D. selecting a rigid tire material

Q.3-27 A scanning plan is a _____

- A. document which outlines the various steps in preparing a procedure
- B. document which defines the most efficient way to analyze the data
- C. document which gives the detailed steps entailed in examining the test item
- D. document which gives the complete history of previous examinations

Q.3-28 In contact testing, the back surface signal from a 2 in. plate was set at full screen height. Passing over a coarse grained area, the back surface signal dropped to 10 percent of the full scale signal. What would be your estimate of the change in attenuation in this local area?

- A. 20 dB/in.
- B. 10 dB/in.
- C. 5 dB/in.
- D. 10 percent/in.

Chapter 4

Practical Considerations

Chapter 4

Practical Considerations

Many issues of a practical nature arise during both routine and specialized ultrasonic inspection activities. Issues of concern include interpretation of echo signals (as viewed on the A-scan), equipment adjustment to expedite interpretations, and set-up conditions for production inspections.

Signal Interpretation

The interpretation of ultrasonic pulses received from test part reflective surfaces can be very complex, depending upon the geometry of the test piece and the wave mode/scan approach being used. The most reliable measure available from an A-scan system is the time of arrival of acoustic pulses, due to its lack of ambiguity when testing fine-grained, homogeneous materials. In contact testing of materials with known and constant sound wave velocities, the time of arrival is directly proportional to the distance between the contact surface and the reflector. The precise time of arrival is usually determined by when the pulse initially departs from the screen baseline. Systems using threshold devices to trigger delay time monitors can be in error, depending upon the slope of the pulses rise time and the level to which the threshold device is set.

The signal peak is less reliable for this time measurement because pulses may spread following passage through dispersive media. Estimating the actual time the envelope of the RE signal reaches a maximum is also a somewhat uncertain approach. Depending upon which portion of the pulse is used for travel time measurements, the estimates of thickness and distance to reflective surfaces can vary by one or more wavelengths.

Signal amplitudes are generally reliable for the resetting of instrumentation, based upon controlled calibration blocks and their reference reflectors. But the amplitude of the pulses received from naturally occurring reflectors has a high level of variability depending on the reflector's orientation and morphology, neither of which are known in most circumstances.

Correlations of signal amplitudes with specific reflectors are generally recognized as a valid means of establishing the level of sensitivity of an ultrasonic system. Thus flat-bottom holes, with cross-sections smaller than the sound beams incident upon them and oriented at normal incidence, do exhibit signal responses that are proportional to the area of the reflector. But correlation with naturally occurring discontinuities of irregular shape and orientation has proven to be less than accurate, largely due to an inability to satisfy the normal incidence requirement and to the fact that the reflecting surfaces are rarely flat and smooth. Where natural discontinuities exhibit these conditions, as with small laminations in plate materials, the area relationship has validity. Although the degree of signal-flaw correlation at a single transducer location is less than desired, observing changes in signal response as the transducer is moved along, across, over, and around a suspect area can suggest if the reflector is round or flat (linear), rough or smooth, parallel or vertical, and filled with materials which have a higher or lower density than that of the surrounding material. Table 4A lists the techniques used in making these determinations.

Finger damping is a technique whereby a moistened finger, placed on the surface of a test piece at a location where sound waves are present, will affect the wave propagation and will

Table 4.1. Signal Interpretation Schemes

Characteristic	Action	A-Scan Response
Orientation (Front Surface)	Rotate, Approach	Maximize signal
Vertical	Translate, Across	"Walking signal"
Flatness	Rotate,	Unidirectional
Spherical	Rotate,	Omni directional
Thickness	Both (many) sides	Thin if one side predominates Graphical plot
Length (large)	Translate in major direction	Drop-off at ends
Depth/width (large)	Translate in minor direction	Drop-off at edges Graphical plot Tip diffraction
Surface Texture		
Smooth	--	Crisp, fast rise
Rough	--	Jagged, wide pulse
Multi-reflector	--	Multi-echoes
Contents	--	RF phase reversal

often be detectable as slight changes in signal amplitudes on the CRT. This technique is very effective in separating collections of signals, particularly when some of them are caused by spurious reflections from corners, weld crowns, or other surfaces which are readily accessible to the inspector.

Causes of Variability

There are many instrument variables which can have a significant bearing on the outcome of a test and the interpretation of data. Horizontal sweep extent and accuracy affect estimates of time duration from initial pulse to significant echoes. These are used as measures of thickness ("straight beam" testing) and slant distance ("angle beam" testing) and should extend over the entire range of interest.

Although amplitude is not a reliable indicator of a natural discontinuity's actual size, due to variations in shape, aspect angles, transmission properties of base materials, and other factors, it

is often indicative of the relative size of many common reflectors and is vital for being able to establish an instrument's settings with respect to a calibration reflector or for re-establishing settings from one inspection to the next.

Ideally, an ultrasonic system should be capable of detecting reflectors throughout the region from the sound entry surface throughout the test item's entire volume. However, the length of the incident sound pulse (due in part to transducer element ringing) represents a distance within which echoes, particularly weak ones, cannot be distinguished from the reflection caused by the entry surface itself. If short duration pulses are used, i.e., if high-frequency, well-damped transducers are used, the near surface resolution is significantly improved over systems using long duration pulses.

In contact testing, the ability to detect reflectors just under the near surface is further aggravated by the "dead zone" that exists immediately after the initial electrical pulse. The dead zone is caused by an inability of saturated electrical components to respond linearly to incoming

signals as a result of their having been over-driven by the initial pulse. The "near-surface resolution" dead cone problem can be solved by testing parts from opposite surfaces rather than from only one side.

Some codes and specifications have reject criteria based on the size of the flaw. Where two reflectors exist in approximately the same plane and are in close proximity to each other, it is important to be able to differentiate one from the other. Systems with very narrow beams are capable of satisfying this requirement and are said to have good lateral resolution. Lateral resolution is principally a function of the search unit's beam width. This factor is very important in imaging systems where clear delineation of small and individual flaws is desired.

Sensitivity is a measure of the ability to detect small reflectors. Systems with high levels of amplification (high gain) are usually systems with a high sensitivity. However, when the ultrasonic system is considered in its entirety, several factors can alter the sensitivity that might be expected for a given combination of instrument, transducer, test material, or discontinuity

of interest. The important factors affecting sensitivity are listed in Table 4.2.

The search unit is the most important component in the UT system. This device determines, to a high degree, the characteristics of the sound beam including shape, near-field length, focal point (if appropriate), and refracted angle. The transducer (with its mounting and backing members) also determines the pulse shape, frequency, and length in conjunction with the electrical exciting pulse and the instrument load imposed on the crystal.

Because of these factors, it is important that the proper search unit be chosen, and each search unit characteristic be checked against the desired values on the UT instrument to be used in the examination. Manufacturers often provide certificates with the measured values deemed important by the manufacturer. These include, but are not limited to, photographs of the RF waveform, the frequency spectrum content, and a distance/amplitude characteristic curve measured on a test block. Usually a value for the damping factor is calculated. Since this factor is not defined the same universally, it may be

Table 4.2. System Factors Affecting Detection Sensitivity

Factor	Effect	Comment
Gain		
Transducer	Conversion efficiency Field concentrators	Coupling Coef .d33, g33 Lenses, beam pattern
Amplifier	Electronic amplification	High linear gain = High sensitivity
Pulse Length	Masks nearby reflectors	Depth resolution, better penetration
Wavelength	Reflectance, directivity	Smaller λ = better sensitivity, resolution, higher noise (poly mtl's)
Signal processing	Gain * bandwidth = constant	Smoothing, filtering, reject reduce sensitivity
Noise sources		
Random	Electrical (outside, inside)	Lights, welders, cranes plus circuit cross-talk, instability
Coherent	Transducer construction Material surface Material homogeneity, isotropy, and geometry	Cross-coupling, damping Coupling Uncertainty of velocity, scatter Geometrical reference surfaces

desirable to determine the definitions used in the calculation. For example, definitions may be based on the number of cycles or half cycles meeting a certain parameter, e.g., the number of negative half cycles in a pulse greater than the amplitude of the first negative cycle. Each of these definitions serves the same purpose in different ways, i.e., to describe the pulse length and shape.

Test item surface condition is an important variable, especially when performing contact tests. A rough surface affects the examination in many ways, including causing difficulty in moving the search unit across the part; causing local variations in the entry angle resulting in scattering the beam; causing reverberations of the sound in the pockets on the surface, resulting in a wide front surface echo with a resulting increase in the dead zone; using excess couplant and making coupling difficult; possibly causing portions of the examination volume to be missed; and causing rapid wear of contact search units.

In some cases, it may be necessary to sand or grind the scanning surface prior to the examination in order to accomplish the test. Rough sand castings, some forgings, and welded surfaces typically require rework prior to the UT test.

Extremely smooth surfaces may be difficult to test using the contact technique because the couplant may not wet the surface. This can lead to air being trapped between the search unit and the part. This phenomenon is readily observed when using transparent angle beam wedges.

Part configuration (geometry) plays an important role in defining each examination's operational parameters and practices. Geometry and access often decide the choice between contact and immersion testing; however, there are no rules which relate the complexity of shape to making the choice. Technique selection is governed by many things such as equipment availability, part criticality, configuration, operator experience, and knowledge; a number of highly symmetrical parts, e.g., plates, pipe, cones, spheres, and cylinders, lend themselves to both immersion and contact automated testing.

Irregularly-shaped parts are often beyond the capability of conventional automated scanning systems and are better left to manual examinations. With the advent of computerized scanners with learning modes, the operator leads the system through one examination and the computer then automatically repeats the examination.

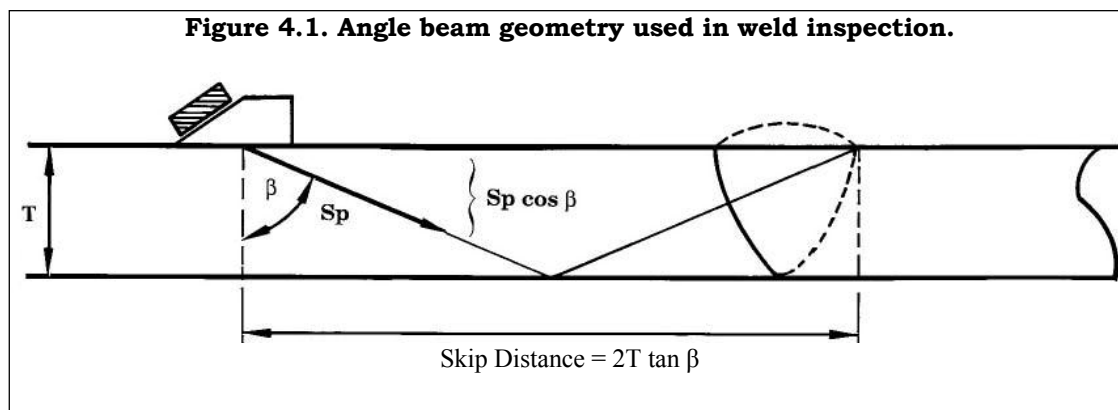
The presence of irrelevant signals from geometric features is a major inspection consideration. The most common of these is the back surface echoes from plate material (where multiple echoes are frequently present). Fortunately, these are easily recognized. In other cases, however, irrelevant echoes such as from the root of a weld, may not be easily differentiated from actual flaw indications. In these cases, careful analysis is required incorporating consideration of beam spread and mode conversion as well as the normal issues of transit time. Changes in beam direction and velocity due to material conditions must be factored into these analyses. Reflections from internal structural features must also be recognized and considered.

Special Issues

The largest application of UT is for flaw detection. It is used in receiving inspection of raw materials, for in-process inspection of items under construction, and for in-service inspections (as part of ongoing maintenance programs). Although most applications involve metallic materials, UT is also found in the inspection of plastics, composites, concrete, lumber products, and affiliated specialty materials.

Weld Inspection

Ultrasonics is a primary method of weld inspection, particularly when major construction projects are involved. Welds, including their heat affected zones, are examined because the probability of failure is higher in these areas than in most base materials. Although weld metal is normally stronger than the base metal, stress risers may occur due to weld contour, processing, or the presence of defects. The weld process itself creates residual stresses which, when added



to applied stresses, may cause cracking due to fatigue or stress corrosion.

Examination of butt welds in materials from about 1/4 to 15 in. thick are normally performed using an angle-beam, shear wave technique because the sound can be oriented at near-normal incidence to the critical flaws, i.e., cracking, inadequate penetration, and fusion. The bodies of the welds can be inspected without removing the weld crown. When part geometry allows, the exam should be conducted from each side of the weld. Refracted angles are chosen according to the fusion line angle, material thickness, or other expected defect orientations.

Figure 4.1 shows the basic geometry used for defining the angles and paths followed by sound beams when doing shear wave (angle beam) testing. As shown, the sound, introduced at an angle which complements the geometry being examined, follows a sound path that often reflects from the opposite surface, particularly for plate-like product forms. The V-shaped path permits inspection looking "down" into the weld in the first leg of the V while the second leg is the region used to look "up" into the weld. By scanning the transducer toward and away from the weld, the sound can be made to interrogate the entire volume from two or more sets of angles.

Analysis of signals observed on the A-Scan display requires converting the information found along the sound path (along the Vee path) into positional data related to the base material and weld centerline. This is done using conventional

trigonometry to solve for equivalent surface distances, e.g., skip distance, or depths below or above the base material surface. For example, for the 1 in. plate shown in the figure and using a 70 degree angle, the skip distance (distance from transducer exit point to location at which center of sound beam reaches the top surface after reflection) is given by

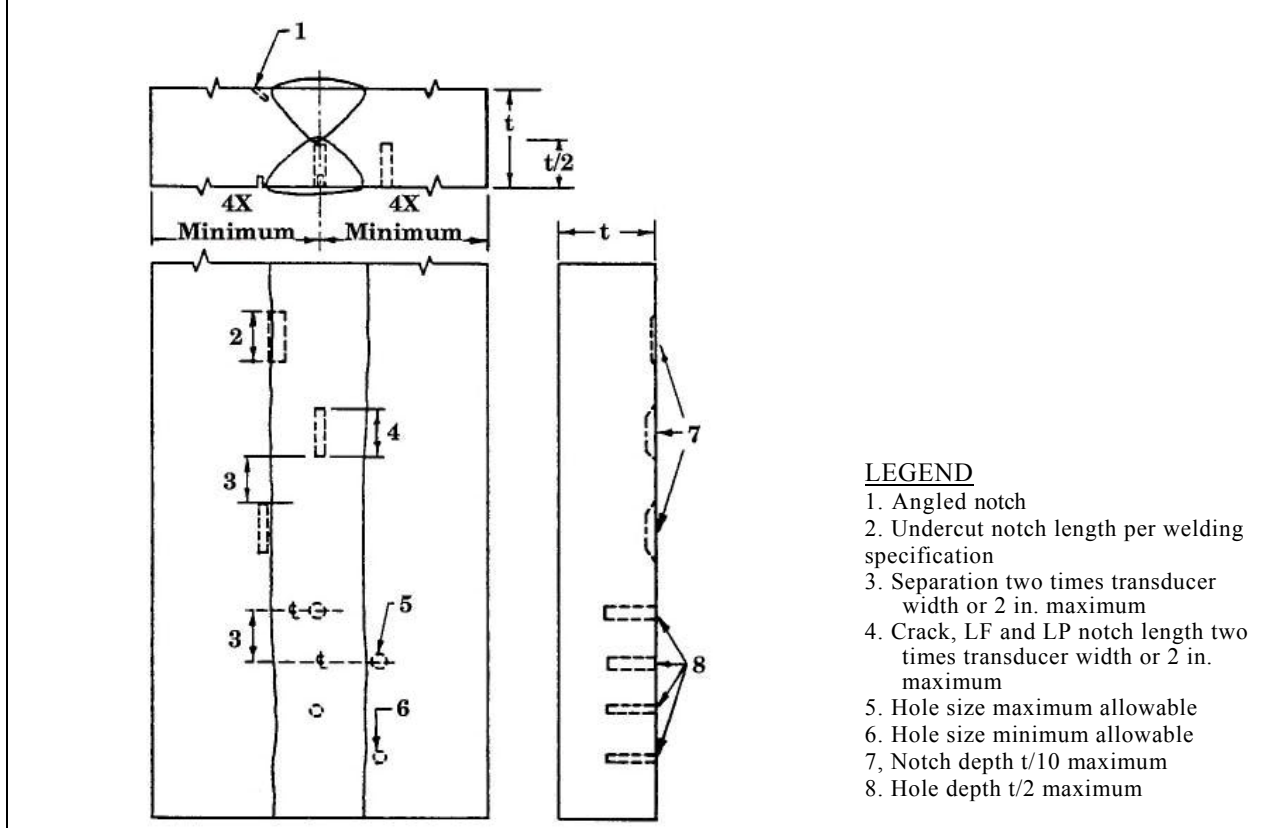
$$2T \tan \beta = 2 \tan 70 \text{ degree} = 5.5 \text{ in.}$$

For this same case, the sound path is given by

$$2T / \cos \beta = 2 / \cos 70 \text{ degree} = 5.85 \text{ in.}$$

Common problems found during weld examination involve rough surfaces (including weld spatter), irregular part geometry (including hidden conditions such as counter-bores in piping systems), and physical inaccessibility (due to insulation and being embedded in reinforcing structures). During production and under some in-service inspections, examinations may be done at elevated temperatures which can alter the effective sound velocity of the material, transducer performance (particularly refracted angles or critical temperature limits), and operator's performance. All of these factors must be addressed and considered in the procedure. Where irregular inner surface conditions exist, interpretation of reflector signals is often very difficult. For example, the presence of a backing bar (placed at the root of the weld in order to assure adequate penetration and fusion) tends to entrap the incident sound waves which reverberate around the bar and eventually exit along the same path by which they entered the backing

Figure 4.2. Reference standard for weld inspection using notches



strip. Thus, strong echo signals are returned to the sending transducer at an apparent depth of slightly more than the thickness of the base material. The interpretation might be that a large defect exists just beyond the root area of the weld on the opposite side of the weld.

Another troublesome welding configuration is introduced by the presence of a counter-bore "ledge", machined or ground into the inner radius of a pair of fitted pipes, so placed in order that their initial fit-up (gap and alignment) is generally uniform. Such a geometry can give rise to strong geometrical reflector signals in the immediate vicinity of the weld root, an area well known for the initiation of stress corrosion cracks in stainless steel piping systems. If the angles of inspection and counter-bore are such that the reflected wave is below the first critical angle, internal mode conversion can take place with a longitudinal wave traveling in a direction other than that of the reflected shear wave.

Figure 4.2 shows the use of notches introduced into a separate sample of the welded structural steel to serve as a mock-up for the weld

inspector to accurately locate where on the CRT echo signals can be expected to appear.

Welds such as fillet welds and dissimilar metal welds may require the application of different techniques in order to examine all portions of these welds and **their** heat-affected zones. Due to the geometry of many fillet welds, particularly those in which incomplete penetration is permitted, ultrasonic testing is usually not recommended. In other cases, such as stainless steel piping, ultrasonic inspection may be successful **in** the base material (a wrought product) **but** not in the weld lone (a cast product).

Immersion Testing

The immersion method of coupling ultra-sound to test parts permits a wide variety of test conditions to be used without the need for custom-designed transducer assemblies, and with consistent coupling characteristics, allowing for imaging of test parts with regular shapes, i.e., plate, rod, cylinder, pipe, and simple forgings, and assemblies such as honeycomb panels.

The flexibility of immersion testing is both a blessing and a bane in that it permits the use of a single set of test equipment (transducers, mostly) to be used for a large variety of inspection protocols (inspection angles, modified beam patterns, regulated scanning patterns, and high sensitivity transducers), but it involves relatively expensive systems and significantly extends the setup time for each inspection.

Alignment of sound beams to test part surfaces is expedited by the use of the multiple reflections which occur as a result of sound being reflected from the water-test part interface back to the transducer face, and re-reflected back and forth between the transducer and the test part. By monitoring these multiple reverberations while angulating the transducer manipulator, the presence of the largest array of multiples assures that the sound beam is aligned perpendicular to the test part's front surface and thus the sound beam is normal to the surface. In immersion testing, because of the large difference between the velocities of sound in water and metallic parts, this alignment is critical because slightly off-axis beams are refracted by a leverage factor of approximately 4:1. Figure 4.3 shows the presence of water multiples as well as the multiple echoes developed within the flat steel plate.

The gain used in immersion testing is rather **high**, due to the large amount of sound energy lost at the water-test part interfaces which are often very different in acoustic impedance. When the transducer is relatively close to an item with parallel surfaces, the CRT often displays an array of multiple reverberations from within the item, as well as from the water multiples. In this case, the water multiples are readily identified by displacing the transducer along its longitudinal axis toward the test item. As the transducer moves, the water multiples will tend to gather closer together as the transducer approaches the test part, tending to "walk through" the test part multiples, and eventually piling up at the first interface signal.

Immersion testing is used in the pulse-echo mode as well as through-transmission. A variation on the through-transmission approach uses a fixed beam reflector placed beyond the test panel and adjusted so that its echo can be detected by the sending transducer in the pulse-echo manner. This delayed reflector-plate signal is indicative of the strength of the sound beam after passing through the panel two times. A weak reflector-plate signal (if properly aligned) - usually signifies a material with a high level of attenuation due to its composition, or the presence of highly attenuating voids or scatterers

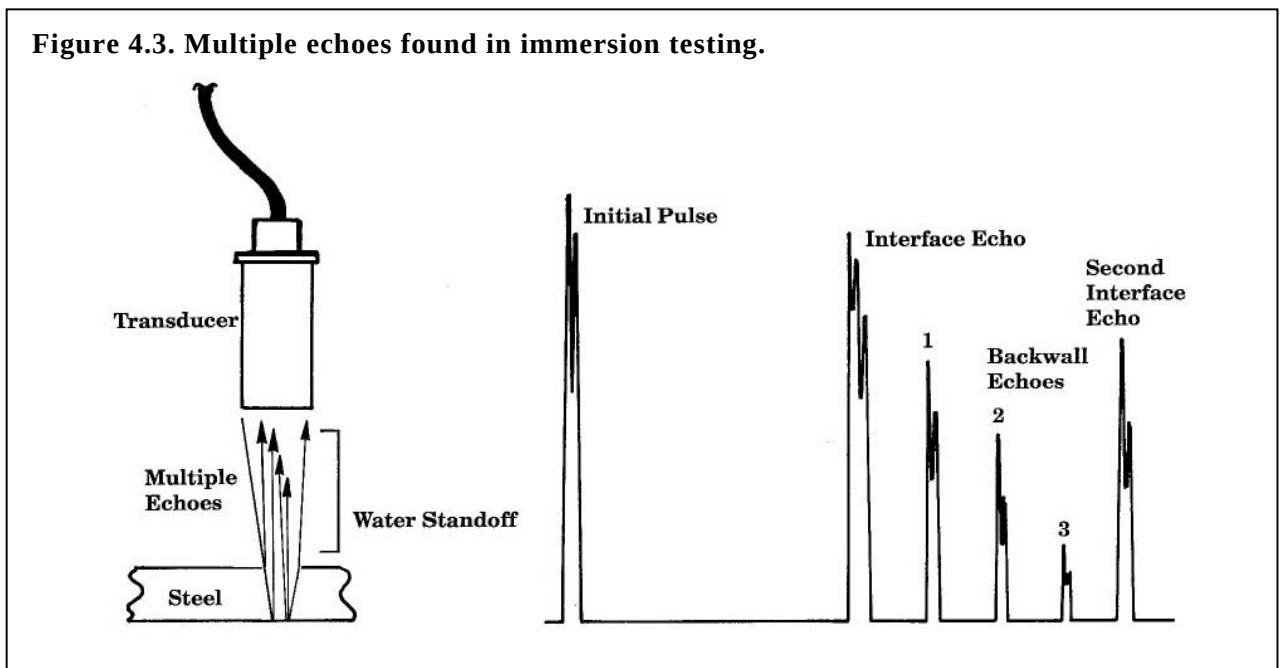
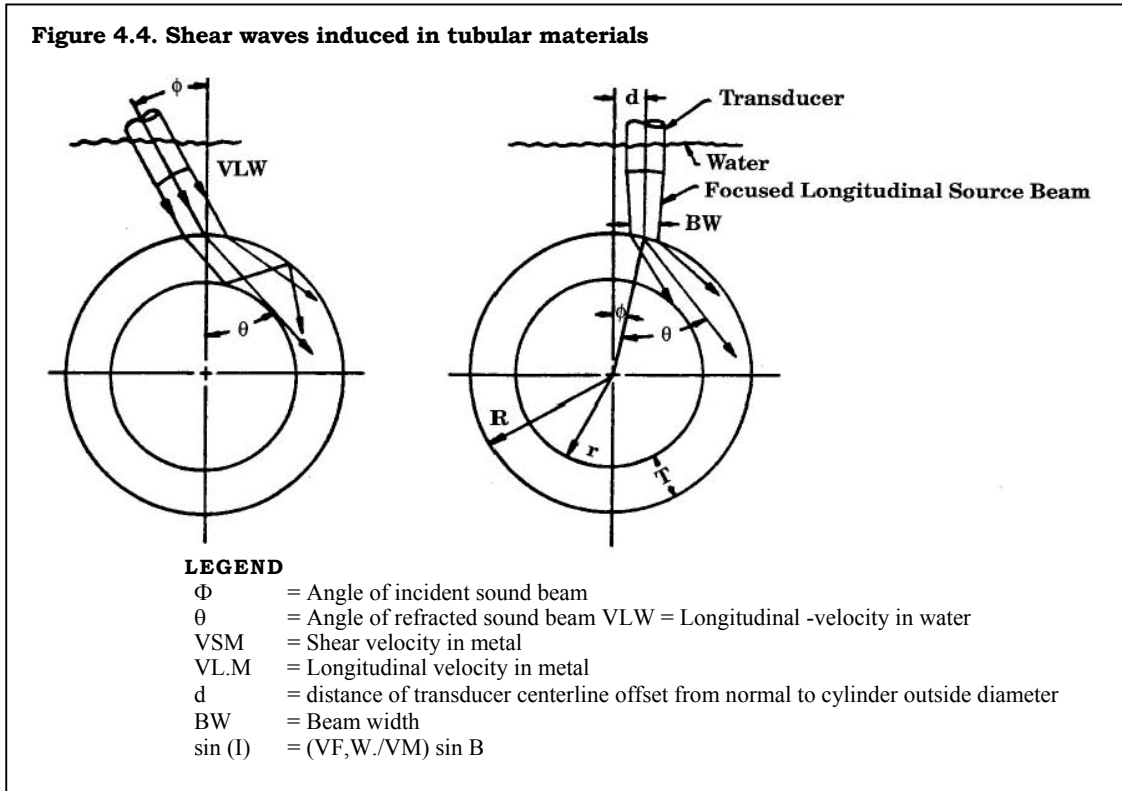


Figure 4.4. Shear waves induced in tubular materials



which may not result in a discrete **back** scattered echo of their own.

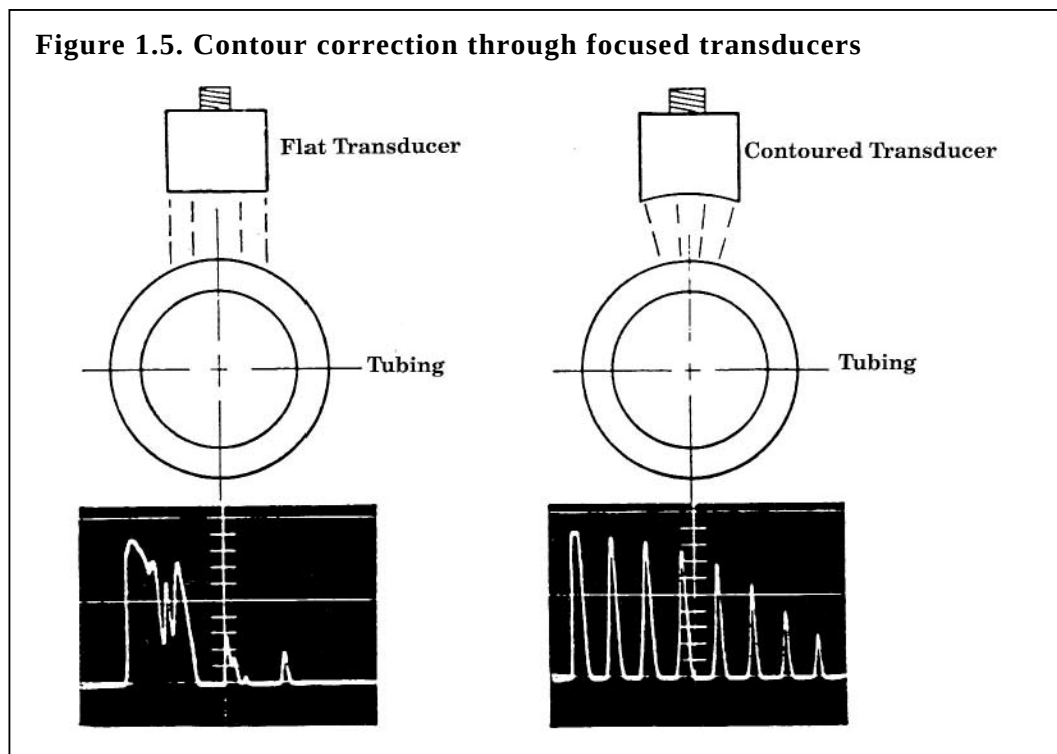
Angle beam, shear wave testing is often achieved by rotating (swiveling or angulating) the transducer with respect to the sound entry surface. For cylindrical items, it can also be done by offsetting the transducer to the point where the curvature of the test part yields a refracted shear wave as shown in Figure 4.4. The curvature of the test surface results in the refraction of the sound beam in a manner that tends to spread the sound with the water-item interface functioning as a cylindrical lens, diverging the beam. Areas with concave surfaces, such as inner radiused forgings, are some-times difficult to inspect because they focus the sound beam into a narrow region, making complete, uniform coverage quite difficult.

It is possible to compensate for some of these contoured surfaces through the use of specially designed transducers or the introduction of contour-correcting lenses applied to flat transducers.

Figure 4.5 shows the effect of contour correction on the A-scan display obtained with and without correction being used. By matching the curvature of the sound beam to the curvature of the tube, a set of well spaced multiple reverberations from within the tube wall is clearly evident.

When using transducers equipped with focusing lenses for the purpose of increasing flaw sensitivity or lateral resolution, the introduction of flat surfaces associated with test parts also distorts the beam pattern, tending to fore-shorten the focal length due to the refraction of the wavefronts entering the higher velocity metallic parts. The focal distance is usually reduced in length equivalent to one-fourth of what it would have been in the water without the presence of the metallic test part. The factor of one-fourth arises from the ratio of the longitudinal wave acoustic velocities within the water and metallic, respectively. Figure 4.6 conceptually demonstrates this effect.

Figure 1.5. Contour correction through focused transducers



The automation of immersion inspections relies on the use of special circuits (gates) that send control signals to recorders, alarms, transporters, and marking devices in response to the presence (or absence) of special ultra-sonic echo response pulses. By using time delay circuits, initiated by either the initial excitation pulse of the pulser/receiver units or by reflections *from the front surface* of the test part, the time of arrival of ultrasonic echoes with respect to benchmark echoes (received from front surfaces, back surfaces or other strategic reflecting surfaces) indicates when discontinuities are present within the test part. The use of front surface gating is a very effective way of having the *gate* follow a slightly curving surface, relieving the need for identical tracking of mechanical positioners and rigid test part surfaces. The reliable triggering of recorders and alarm systems relieves the operator of continual monitoring and permits other activities to take place while immersion testing is progressing.

Problems found in automatic immersion testing include the continual maintenance of the condition of the water (corrosion inhibitors,

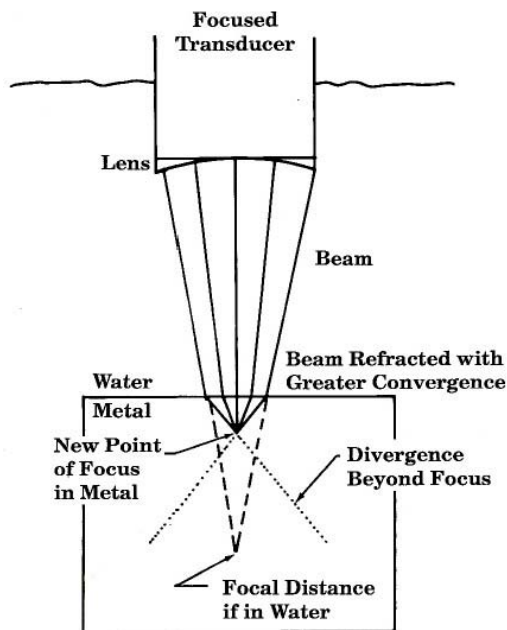
anti-foulants, wetting agents) and the outgassing of test parts during testing. The outgassing is most troublesome due to the formation of bubbles on the surfaces of materials upon their introduction in the water tanks. Although wiping them off removes much of the problem, the bubbles tend to continue forming even after being submerged for relatively long periods of time. Upon test part removal, care must be taken to thoroughly dry and protect the items since they will be prone to suffer corrosive attack. As with any heavy-duty mechanical positioning system, wear and backlash in drive trains tend to introduce a mechanical hysteresis which can affect the results expected from C-scan recorders and other image generating devices.

Production Testing

Immersion testing is the preferred approach to automated testing due to the absence of contact coupling problems, minimum deterioration of performance due to use, and ability to use high frequency systems without concern for fragile transducer fracture.

As with many industrial processes, UT testing is realizing the benefits of computer

Figure 4.6. Second lens effect of metallic test parts when using focused transducers.



integration in test applications and the interpretation of results. This phenomenon has opened many previously inaccessible areas of testing. Computer integration is providing examination of complex shapes, real-time analysis of data with accept/reject decisions, different data displays, signal analysis and pattern recognition, a high degree of operator independence, and - high speed calibration. Computer integration is an expensive and time-consuming activity requiring considerable engineering and development effort.

Computer integration into imaging processes offers advanced data analysis capabilities because of its ability to visualize the size, shape, and location of reflectors. Images can be rotated and otherwise manipulated to maximize the

information available to the analyst. Through color or gray scale coding, amplitude and depth information can be integrated into the displays to enhance the qualitative interpretation of the data. Quantitative information is also available, but as in the case of virtually all nondestructive inspection methods, it is correlated to material performance only through inference and not through direct measurement. The prime advantage to the analyst is the simultaneous display of large amounts of both signal response and positional data.

In-service Inspection

In-service inspection and maintenance flaw detection are used primarily to locate service-induced flaws such as fatigue and other load-induced cracks. In-service inspection is performed on equipment used to produce the product rather than on the product itself, and is used extensively in the nuclear power and petrochemical industry. This service is often performed under poor working conditions, requiring highly qualified personnel and appropriate techniques.

Field testing is a conglomerate of applications and techniques used in a variety of industries for a variety of reasons. Numerous testing laboratories provide field testing services and can provide quick response with qualified personnel. Ultrasonic field testing is used on pipelines, building construction, maintenance, and failure analysis. Field testing techniques are many and varied, and change from day to day, depending upon the particular job at hand; hence the requirement for qualified personnel.

Field techniques include straight (normal) beam, angle beam, and surface waves. In construction, these are used to detect fabrication defects in maintenance; service induced defects and corrosion are the usual culprits. Most of this work is manual because the applications are so varied and job site inspection is required.

Chapter 4 Review Questions

Q.4-1 In a through-transmission, immersion examination of an adhesively bonded lap joint, the signal is noted to decrease in amplitude in a small area of less than 1/16th in. diameter as recorded on a C-scan. What condition might cause this indication?

- A. a bubble on the surface of the joint or an unbonded spot in the joint
- B. the joint is tightly bonded in this area
- C. there is nothing that could cause this condition-it is an anomaly
- D. the adhesive has melted in this area causing an increase in sound transmissivity

Q.4-2 Advantages of computer controlled ultrasonic testing include _____

- A. lower capital equipment costs
- B. high dependence of the test results on the capability of the operator
- C. real-time analysis of test results
- D. no need for instrument calibration even though such action is required by the specification

Q.4-3 During the test of a fiberglass-epoxy composite, numerous echoes are recorded in the pulse-echo mode. What action should be taken?

- A. the part should be rejected because all echoes are from flaws
- B. the part should be rejected because the supervisor was not there to give advice
- C. the part should be accepted because all composites will have numerous echoes
- D. the procedure should be consulted to determine the analysis technique and the accept/reject criteria

Q.4-4 An immersion, pulse-echo test is performed on a thin adhesively bonded joint between a composite material and an aluminum substrate. The sound beam enters the joint normally and from the composite side. The amplitude gate is set on the interface between the composite and the aluminum. If the joint is unbonded, the signal should:

- A. decrease, because water has a lower velocity than the aluminum
- B. decrease, because water in the unbond will conduct sound better than air

- C. increase, because air in the unbonded area will reflect more sound energy than the aluminum
- D. increase, because the composite will resonate

Q.4-5 Three major sources of noise which interfere with the signals on the CRT are _____

- A. front surface roughness, hydraulic motors, and enlarged grain structure
- B. back surface roughness, electric motors, and decreased grain structure
- C. depth, size and location of defect
- D. front surface roughness, arc welding operations, and enlarged grain structure

Q.4-6 A single Vee, butt weld in a 3 in. plate is being examined using a 60-degree shear wave. An indication on the CRT appears at a sound path distance of 9 in.. At the same time the exit point of the transducer is 7.8 in. from the centerline of the weld. This suggests the reflector could be

- A. a crack in the near side HAZ
- B. lack of fusion at the weld/base material interface
- C. a slag inclusion in the center of the weld
- D. an undercut condition on the far side of the weld

Q.4-7 Under the conditions above, but with the indication at a 6 in. sound path distance and with the exit point 5.2 in. from the weld centerline, another strong indication is received indicating a probable reflector in the _____ the weld.

- A. root area of
- B. crown area of
- C. midsection of
- D. base metal adjacent to

Q.4-8 Under the conditions above, but with the indication at a sound path distance of 9 in. and with the exit point 8.1 in. from the weld centerline, the reflector lies in a plane that is _____ in. from the center of the weld.

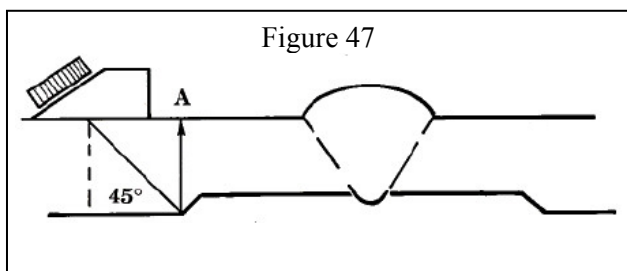
- A. 0.1 (on the far side)
- B. 0.3 (on the near side)
- C. 0.3 (on the far side)
- D. 0.5 (on the near side)

Q.4-9 Under the conditions above, the reflector is at a depth of _____ (measured from the transducer side).

- A. 1.5 in.
- B. 1.0 in.
- C. 2.0 in.
- D. 2.25 in.

Q.4-10 In a thick-walled piping weld inspection, the counter-bore on the ID reflects the incident 45-degree shear wave so that it strikes the top surface (outer diameter) at normal incidence. In order for this to happen, the taper on the counter-bore must be _____. (see Figure 4.7)

- A. 30 degrees
- R. 45 degrees
- C. 11.25 degrees
- D. 22.5 degrees



Q.4-11 Under the above conditions, an L-wave is internally mode converted at an angle with the sin 13 given by _____

- A. $\sin \beta = (V_L / V_s) \sin (\text{incident angle})$
- B. $\sin \beta = (V_L / V_s) \sin 45 \text{ degrees}$
- C. $\sin \beta = (V_s / V_L) \sin 90 \text{ degrees}$
- D. $\sin \beta = 4 \sin (\text{incident angle})$

Q.4-12 A pipe being examined automatically using immersion techniques (with mode conversion to a 45-degree shear wave at the pipe wall-water interface) is experiencing a wobbling displacement (transverse to the pipe axis) of +10 percent of its nominal offset value. The pipe is steel ($V_s = 3.2$; $V_w = 1.5$). The corresponding change in inspection angle would be:

- A. 11-14 percent
- B. 13-12 percent
- C. 10-10 percent
- D. 14-10 percent

Q.4-13 During production testing, a rod is passing under a transducer in a stuffing box (immersion testing). What is the expression that relates pulse repetition rates (of the UT instrument, i.e., PRR) with the longitudinal speed of travel (V_p) of the test part, given a transducer of width D ?

- A. $D = V_p / \text{PRR}$
- B. $\text{PRR} = D * V_p$
- C. $V_p = D / \text{PRR}$
- D. none of the above

Q.4-14 An inspection specification calls for three hits of an echo in order for the flaw to be considered valid and for the alarm to sound. The maximum axial speed of test part movement is therefore _____ for a 1 in. diameter transducer (assume no beam spread) and a PRR of 600 pulses per sec (PPS).

- A. 1800 in/sec
- B. 600 in/sec
- C. 300 in/sec
- D. 200 in/sec

Q.4-15 A 1.5 in. butt weld is to be examined from both sides using a 70-degree shear wave. The scan program calls for being able to inspect 3 legs (1.5 vee paths). Weld access for completing this pattern will require $\pm$ _____ plus the physical dimensions of the transducer assembly.

- A. 4.50 in.
- B. 8.24 in.
- C. 12.36 in.
- D. 24.73 in.

Q.4-16 The sound path sweep setting on the 10 Division CRT for the above case should be:

- A. 1.35 in./div.
- B. 1.00 in./div.
- C. 1.25 in./div.
- D. 0.50 in./div.

Q.4-17 A 0 degree axial test is being performed on a steel railroad axle 8 feet long and 6 in. in diameter. A strong but unsteady signal is seen near the center of the CRT screen. A similar signal is seen from the other end of the axle. The following conditions are given:

Screen Distance: 10 feet (12 in./Div), Damping: Minimum, Gain: 85 dB, Pulse Repetition Rate:

2000 PPS, Frequency: 2 MHz, Range: 50 in.,
Reject: Off, Filter: Off, Sweep Speed: As Required,
Sweep Delay: As Required

What action should the operator take?

- A. record the indication and notify supervisor
- B. change the PRR to 1000 and observe the effect
- C. compare the signal to the reference standard
and reject the axle if the reference level is
exceeded
- D. determine if the signal responds to finger
damping by touching the opposite end

Q.4-18 A 10-foot long turbine shaft is to be inspected
from one end with 0 degree, longitudinal wave for
radial, circumferential fatigue cracks in an area
between 90 and 110 in. from the inspection end. The
available instrument screen can display a maximum of
80 in. How should the operator proceed?

- A. give up
- B. set up 20 in. screen and delay the start to 90 in.
- C. set up an 80 in. screen and delay the start to 30 in.
- D. assume there are no cracks and turn in a
report

Chapter 5

Codes and Standards

Chapter 5

Codes and Standards

Every ultrasonic examination should be governed by one or more procedures that are structured to comply with the rules and criteria of applicable codes, standards, and/or specifications. Simple maintenance tasks such as thickness measurement for corrosion detection may not be governed by any regulation, but a specific procedure should still be followed in order to assure the gathering of valid and accurate data.

Typical Approaches

Ultrasonic examinations in a critical or well-regulated industry are often covered by multiple documents. For example, the nuclear power generation industry uses procedures written in accordance with the American Society of Mechanical Engineers (ASME) Code. The Code, in turn, is supported by published applicable American Society of Testing and Materials (ASTM) Standards. Sometimes these are augmented by company, customer, or Nuclear Regulatory Commission (NRC) Regulatory Guides, i.e., supplemental detailed specifications. In order to meet the intent of these documents as well as their obvious stated requirements, the Level III must be able to understand the point of view that led to the statements within the documents and be able to assure an employer that ultrasonic inspection activities, documented in straightforward procedures, are in compliance with the entire spectrum of applicable codes and standards.

The manner in which requirements are stated in codes and standards varies from document to document. Some, such as the ASTM standards, tend to emphasize the manner by which inspection

activities are to be conducted, but leaves the issue of acceptance criteria to be decided between buyer and service organization. In this way, the actual procedures to be followed are left up to the senior technical personnel who must agree upon an appropriate set of acceptance criteria and related operational issues.

In the ASME Code, one section of the Code (Section V) serves the same purpose as the ASTM standards and even uses some of them as the technical basis for ultrasonic activities. Because the Code addresses several levels of component criticality, however, acceptance criteria, requirements for personnel certification, and definition of what will be inspected are reserved for other sections, namely the product-specific referencing sections. For example, Sections III (for new Nuclear construction), VIII (for new Pressure Vessels construction) and XI (for Nuclear In-service Inspection) define the acceptance criteria and personnel certification issues completely separate from Section V, Nondestructive Examination. In order to adequately address the ultrasonic inspection requirements in this case, all applicable sections of the Code, including the supplemental Code Cases that clarify specific issues, must be considered when operating procedures are being prepared to meet this well-known code.

In the above cases, a fair amount of latitude is given the user of the codes and standards in regard to the details of assessing whether an item is acceptable or not. The American Welding Society (AWS) Structural Welding Code (used in building, bridge, and oil rig inspection) is far more prescriptive in the manner by which transducers shall be selected, in which regions of specific welds they are to be used, what compensation for attenuation and beam spread are to be

Table 5.1. Typical Code and Standard Requirements

Issue	Approaches	Examples
Transducer selection	Ranges (size and angle) Prescribed angles Angles for each case	...transducers between 40 & 80 degrees ...transducers of 45, 60, 70 degrees 45° in mid-section, 70° near surface
Scan techniques	General coverage intervals overlap Scanning levels Rates	...scan in two orthogonal direction ...use 9-inch centers for grid ...overlap each pass by 10% of active area ...scan sensitivity to be 6db above ref. ...maximum scan rate of 6 inches per sec.
Calibration	Instrument Transducers Distance correction schedule	...vertical, horizontal linearity ...beam location {TIM, depth resolution, response from SDH , FRH , notch ...set UAC at 80% FSH , electronic settings ... recalibrate at start , shift, changes
Special problems	Component curvature Transfer	Use fig xis to correct for curved items Use dual transducers to set transfer
Reporting	Formats/forms Analysis Authorizations	Form xyz to be used in recording data Classification of reflector found by .. All reports signed by Level 11 & III
Acceptance criteria	General types' Dimensions Collections	Reject all cracks and lack of fusion Reject slag over 3/4 in 2" plate Reject pure spacing of .3 within 2"
Personnel certification	Per undefined procedure Per SNT-TC-1A Per MIL-STD-410 or 250-1500	Supplier to have certification program. Written practice to SNT-TC-1A, 1988 Procedure per
Records of examination	List of documentation Retention period	Final documentation shall include Supplier to retain records for 5 years

used in analyzing inspection results, and how , welds shall he laid out and marked.

In a similar vein, many military standards, because of their highly restricted applications to certain components and configurations, tend to establish more structured approaches to specific configurations of test parts and require inspection personnel to use these customized approaches in conducting ultrasonic inspections.

Table 5.1 lists several of the typical items included in codes and standards which need to be addressed as elements of the manner in which ultrasonic inspection procedures are to be

carried out. For example, an ultrasonic procedure, as cited in some requirements must address the following items: (1) instrument (selection, operating ranges), (2) calibration standard (tie-in to test materials), (3) search unit type, size, frequency (wave geometry), (4) screen settings (metal path), (5) area to be scanned (coverage intensity), (6) scanning technique (manual/coupling/automatic), (7) indications to be recorded (minimum sensitivity), (8) data record format (forms to be followed), (9) accept/reject criteria (basis or specification reference), and (10) personnel qualifications (certifications). The degree to which these and other items are controlled is usually dependent upon the criticality of the application.

Summaries of Requirements

Excerpts of contemporary specifications, taken from both commercial and military practice, are displayed on the following pages in order to gain an overview of their typical contents and to be used as source materials for questions listed at the end of this section. They are not complete in their coverage and should not be considered a surrogate for the original issues of these documents.

ASTM (American Society for Testing and Materials)

ASTM standards are largely structured to define the basic operations which are to be done in conducting nondestructive inspections in an orderly and technically sound manner and often with regard to specific materials. However, because they are intended to be used in many different situations, the details of operational practices are often left to supplemental contractual agreements between buyer and seller of the inspection services. Thus, some of the requirements of these standards tend to serve as recommendations for specific actions or candidates for requirements; if not, alternates are agreed to by the buying and selling participants.

On the following page is an excerpt from ASTM A 609. "Standard Specification for

Longitudinal Beam Ultrasonic Inspection of Carbon and Low-alloy Steel Castings." It has defined a system of reference blocks using flat-bottom holes, which can be used as the basis for developing distance-amplitude corrections and establishing a reference sensitivity for straight beam inspection systems to be used on cast steel components. It further defines conditions under which inspections are to take place (material conditions, scan rates, DAC [ARL] development, reporting requirements), but it does not give specific information regarding recalibration intervals, quality levels, or personnel certification. These are, in large part, left up to the buyer to include as supplemental requirements,

(Excerpts Taken from ASTM A 609*)

Standard Specification for Longitudinal Beam Ultrasonic Inspection of Carbon and Low-Alloy Steel Castings

1. Scope

1.1 This specification covers the standards and procedures for the pulse-echo ultrasonic inspection of heat-treated carbon and low-alloy steel casting by the longitudinal-beam technique.

1. Basis of Purchase

2.1 When this specification is to be applied to an inquiry, contract, or order, the purchaser shall furnish the following information:

2.1.1 Quality levels for the entire casting or portions thereof.

2.1.2 Sections of castings requiring inspection, and

2.1.3 Any additional requirements to the provisions of this specification.

3 Equipment

3.1 Electronic Apparatus:

.. Pulse-echo, 1-5 MHz. linear $\pm 5\%$ for 75% of screen height.

3.2 Transducers:

L-wave, 1-1 1/8 dia, 1 inch square; prefer 1 MHz beyond 2 inch depth.

3.3 Reference Blocks:

FBH, #16, DAC -- 1-10 inch, cast materials that have a metallurgical structure similar to the castings being inspected. Other blocks may be used provided they are proven to be acoustically equivalent to the cast steel. The hole bottom shall be cleaned and plugged. Each block identified. Block specifications: 32 mm, flat/parallel to within 0.001 inch, hole diameter 1/4 0.002 inch, perpendicular within 30 min.

4 Personnel Requirements

4.1 The seller shall be responsible for assigning qualified personnel.... a qualification record shall be available upon request.

5. Casting Conditions 5.1 Heat treat before

UT. 5.2 Surfaces shall be free of interference.

6. Test Conditions 6.1 Each pass of transducer to overlap. 6.2 Rate less than 6 inch/second,

7. Procedure

7.1 Adjust sweep to put back wall at least halfway across the CRT.

7.2 ...Mark the FBH indication height for each of the applicable blocks on the CRT screen. Draw line through indication marks. Set peak at 3/4 screen height. This is the amplitude reference line (ARL). 7.3 ...Use transfer mechanism to compensate for surface roughness differences. Use back wall reflection from block and casting in same thickness, conditions.

7.4 ...Attenuator only control that can be changed during

inspection. Signals may be increased for visibility but returned to base level for signal evaluation Calibration rechecked periodically using transfer block as basic reflector.

7.5 ...Regions having parallel walls and exhibiting loss of back reflection shall be rechecked and treated as questionable until the causes) is resolved using other techniques.

8. Data Reporting

8.1 ...Total number, location, amplitude and area of all indications equal to or greater than 100 percent ARL, questionable areas (7.5), testing parameters and sketch showing un-inspected areas and location and sizes of reportable indications.

9. Acceptance Standards

9.1...Criteria for individual castings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in production of the particular type of casting.

9.2 Acceptance quality levels shall be established between purchaser and manufacturer on the basis of one or more of the following criteria.

9.2.1 No indication equal to or greater than that specified in one of the quality levels listed in Table XI, or

9.2.2 No questionable areas from paragraph 7.5, unless proven acceptable by other means.

9.3 Other means may be used to establish the validity of a rejection based on ultrasonic inspection.

Table XI Rejection Level

Quality Level	Area inch ²
1	0.8
2	1.5
3	3
4	
5	8
6	12
7	16

Notes:

Table XI applies to signals above the 100% ARL line.

1. The areas refer to casting surface area over which a continuous indication exceeding ARL exists.
2. Beam spread and curvature must be considered where long distances and curved castings are involved.

*Extracted, with permission, from the Annual Book of ASTM Standards, copyright American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASME (American Society of Mechanical Engineers)

ASME has structured its nondestructive testing requirements as part of the Boiler and Pressure Vessel Code. This comprehensive set of rules defines the allowable design practices, materials, construction practices, examination approaches, and documentation needed to assure consistent construction of new boilers, pressure vessels, and ancillary components including piping systems, containment systems, and support systems. The Code is subdivided into sections devoted to specific classes of components (pressure vessels, boilers, piping) and supporting technologies (welding, non-destructive examination, materials). Thus items "constructed in accordance with the Code" often must satisfy a multitude of requirements. The following pages include brief excerpts from

Section V, "Nondestructive Examination," as well as very brief examples of how the referencing sections of the Boiler and Pressure Vessel Code are used for the introduction of specific requirements. An example of ultrasonic testing of ferritic cast materials was chosen to compare the ASTM specification and the modified set of requirements of Sections III and V.

The important area of weld inspection is included to highlight the use of special purpose calibration blocks (as opposed to commercially available standard calibration blocks, i.e., the IIW block) and to describe methods of verifying instrument linearity and accommodating test part curvatures.

(Excerpts Taken from ASME Boiler and Pressure Vessel Code*)

Section V (Nondestructive Examination)

Article 5 - Ultrasonic Examination Methods for Materials and Fabrication

T-510 SCOPE

This Article describes or references requirements which are to be used in selecting and developing ultrasonic examination procedures for welds, parts, components, materials and thickness determinations. This Article contains all of the basic technical and methodological requirements for ultrasonic examination. When examination to any part of this Article is a requirements of a referencing Code Section, the referencing Code Section shall be consulted for specific requirements for the following.

Personnel Qualification/Certifications
Procedure Requirements and/or Techniques
Examination System Characteristics
Retention and Control of Calibration Blocks
Acceptance Standards for Evaluation
Extent and Retention of Records
Report Requirements
Extent of Examination and/or Volume to be Scanned

T-522 Written Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable. (a), (I), (O), ... (I), (m), (n), (O)

T-523.1 Examination Coverage

10% overlap of piezoelectric element
Rate 56 in/sec unless calibrated otherwise

T-530 EQUIPMENT AND SUPPLIES

Frequency - (1-5 MHz)
Screen Linearity - $\pm 5\%$ in 20-80% range
Control Linearity - $\pm 20\%$ amplitude ratio
Check Calib. at beginning, end, personnel change, suspected malfunction
Linearity methodology prescribed.

T-540 APPLICATIONS

T-541 Material Product Forms

Plate, Forgings-Bars, Tubular Products

T-541.4 Castings. When ultrasonic examination of ferritic castings is required by the referencing Code Section, all sections, regardless of thickness, shall be examined in accordance with SA-609: supplemented by T-510, T-520, as well as T-541.4.1, T-541.4.2 and T-541.4.3

T-541.4.1 Equipment. Transducer = 1-1 1/8 dia, 1 in² 1 MHz, others allowed if sensitivity o.k.

T-541.4.2 Calibration

Blocks - same material specification, grade, product form, heat treatment, and thickness $\pm 25\%$. Surface representative

L-Wave - per SA-609

S-Wave - per Figure plus other holes, notches for reference.

Method - Straight Beam per SA-609 exclusive of paragraph 7.3 (transfer method).

- Angle Beam 80% peak, SDH DAC curve from block

T-541.4.3 Examination.

per SA-609 plus...

a) A supplementary angle beam examination shall be performed on castings or areas of castings where a back reflection cannot be maintained during the straight beam examination, or where the angle between the front and back surfaces of the castings exceeds 15 deg.

b) The requirements for extent of examination and acceptance criteria shall be as required by the referencing Code Section.

NB-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-541.4 of Article 5 of Section V.

NB-2574.1 Acceptance Stds.

(a) The Quality Levels of SA-609 shall apply per

1) Level 1, $T < 2$ in.

2) Level 3, $2 \leq T \leq 4$ in.

3) Level 4, $T > 4$ in.

(b) Supplemental Requirements

1) Length vs. Level

Level 1, 1.5 in.

Level 2, 2.0 in.

Level 3, 3.0 in.

Level 4, 3.0 in

2) Q Level 1 applies to first inch of any volume of material.

3) Measured change in depth up to lesser of one-half wall or 1 in.

4) Two or more indications in the same plane, separation < longest dimension, within (b)(1),

5) Two or more indications greater than next higher Q-level permits.

Excerpts from Section 111(Nuclear Construction), a sample of a referencing Code section.

*Extracted, with permission, from the ASME Boiler and Pressure Vessel Code, copyright American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

T-541.5 Bolting Material

T-542 Welds

Requirements for UT of full penetration welds in wrought and cast materials including detection, location, and evaluation of reflectors within the weld, heat affected zone, and adjacent material. Covers ferritic products and pipe. Austenitic and high nickel alloy welds covered in T-542.8.5

T-542.2 Calibration

Basic Calibration Block

Material - Same product form and material specification or equivalent P-Number grouping. P-Nos. 1, 3, 4, and 5 are considered equivalent for UT. Test with Straight Beam.

Clad - Same welding procedure as the production part. Surface representative.

Heat Treatment - At least minimum tempering treatment of material spec for the type and grade and postweld HT of at least 2 hr.

Geometry - see Figure 5.1

Curvature - >20 in. dia, considered flat
- <20 in. dia, see Figure 5.1

System Calibration

Angle Beam (Ref Article 4, Appendix B)

- a) sweep range - 10% or 5% full sweep
- b) distance-amplitude correction - 20%±12dB
- c) position
- d) echo from surface notch

Straight Beam (Ref: Article 4, Appendix C)

- a) sweep range - 10% or 5% full sweep
- b) distance-amplitude correction - 20%±12dB

Frequency

- a) change of system component
- b) before, end of examination (series), each 4 hrs. and at personnel change.

T-542.6 Welds in Cast Ferritic Products...

Nominal frequency is 2.25 MHz, unless material requires the use of other frequencies. Angle selected as appropriate for configuration. DAC not required in first one-half vee path in material less than 1 in. thick.

T-542.7 Examination of Welds

Base Metal - Free of surface irregularities.

- Scan with L-wave for laminations at 2X sensitivity.

Longitudinal Reflectors - Manipulate, rotate, perpendicular to weld axis at 2X sensitivity over reference level.

Transverse Reflectors - Manipulate along weld at 2X from both directions.

T-542.7.2.5 Evaluation

An indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-542.8.5 Austenitic and High Nickel Alloy Welds

Ultrasonic examination is more difficult than in ferritic materials due to variations in acoustic properties of austenitic and high nickel alloy welds, even those in alloys of the same composition, product form, and heat treatment. It may, therefore, be necessary to modify and/or supplement the provisions of this Article in accordance with T-110(c) when examining such welds.

T-580 EVALUATION

With DAC, any reflector which causes an indication in excess of 20% of DAC to be investigated to criteria of referencing Code.

T-590 REPORTS AND RECORDS

A report shall be made indicating welds examined, locations of recorded reflectors with operator ID. Records of calibrations (instrument, system, cal block ID) shall also be included.

UW-53 TECHNIQUE FOR ULTRASONIC EXAMINATION OF WELDED JOINTS

Ultrasonic examination of welded joints when required or permitted by other paragraphs of this Division shall be performed in accordance with Appendix 12...

Appendix 12 ULTRASONIC EXAMINATION OF WELDED JOINTS

12-1 SCOPE

This Appendix describes methods which shall be employed when UT of welds is specified in this Division. Article 5 of Section V shall be applied for detailed requirements. A certified written procedure is required.

12-2 PERSONNEL QUALIFICATION - SNT-TC-1 A

12-3 ACCEPTANCE-REJECTION STANDARDS

All indications over 20% DAC shall be investigated to determine shape, identity, and location.

Rejection criteria:

- a) interpretations of crack, lack of fusion or incomplete penetration, regardless of length.
- b) liner type reflectors exceeding the reference level and the length exceeds
 - 1) 114 in. for T<314 in.
 - 2) T/3 in. for 314<T≤2 114 in.
 - 3) 314 in. for T>2 114 in.

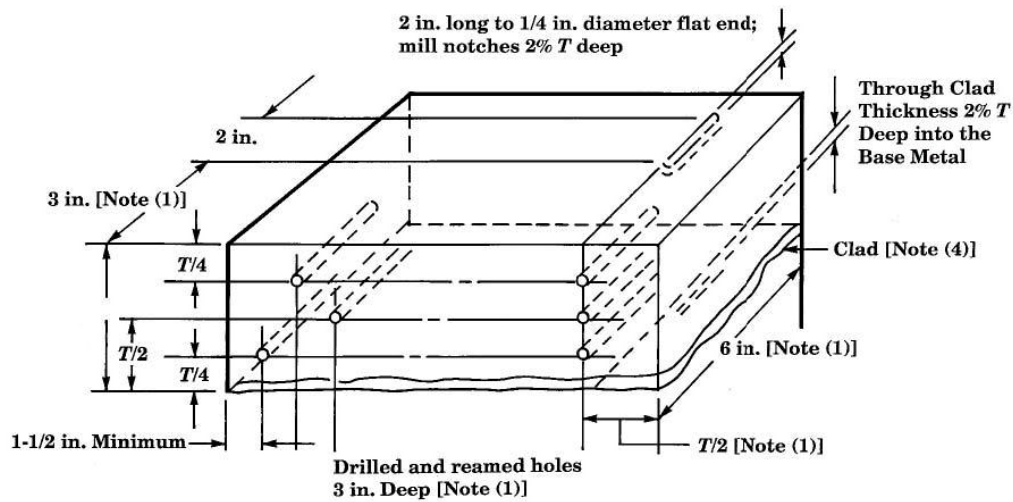
If the weld joins two members having different thicknesses at the weld, T is the thinner of these two thicknesses.

12-4 REPORT OF EXAMINATION

Retain report for 5 years. Include required entries from Section V plus a record of repaired areas and a record of all reflections from uncorrected areas having responses that exceed 50% of the reference level including location, response level, dimensions, depth below surface and classification.

(Excerpts from Section VIII (Pressure Vessels))

Figure 5.1 Basic calibration block.



Weld Thickness (t)	Basic Calibration Block Thickness (T)	Hole Diameter [Note(3)]
Over 2 in. through 4 in.	3 in. or t	3/16 in.
Over 4 in. through 6 in.	5 in. or t	1/4 in.
Over 6 in. through 8 in.	7 in. or t	5/16 in.
Over 8 in. through 10 in.	9 in. or t	3/8 in.
Over 10 in. through 12 in.	11 in. or t	7/16 in.
Over 12 in. through 14 in.	13 in. or t	1/2 in.
Over 14 in.	[Note (2)]	[Note (2)]

Notes:

- (1) Minimum Dimensions.
- (2) For each increase in thickness of 2 in. or fraction thereof, the hole diameter shall increase 1/16 in.
- (3) The tolerances for the hole diameters shall be $\pm 1/32$ in.; tolerances on notch depth shall be ± 10 and $\pm 20\%$; tolerance on hole location through the thickness shall be $\pm 1/8$; perpendicular tolerance on notch reflecting surface shall be ± 2 deg.
- (4) Clad shall not be included in T.

7-593 Examination Records

(a), (b), (c),... (k), (l), (m) lists information to be included such as procedures, equipment, personnel, and map of indications.

Appendix I - Screen Height Linearity

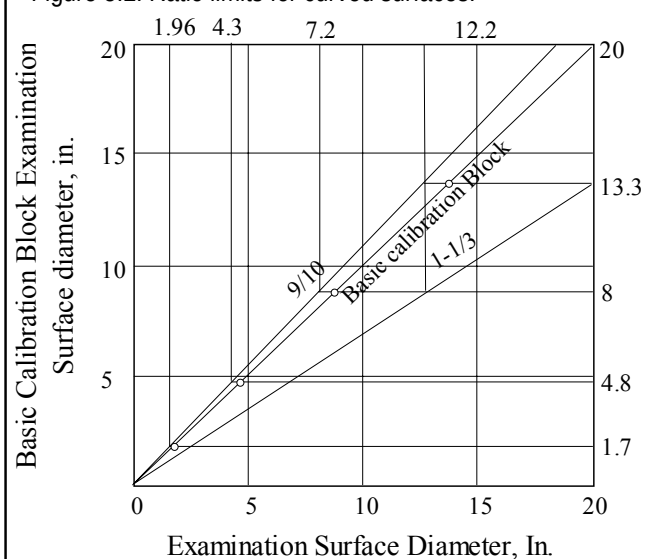
Get dual signal on screen with amplitude ratio of 2:1, with the larger set at 80% FSH. Adjust gain to successively set the larger indication from 100% to 20%, in 10% increments (2dB steps) and read smaller indication at each setting. Reading must be 50% of the larger, within 5% FSH.

Appendix 11 - Amplitude Control Linearity

Get single signal on screen and change gain settings in accordance with table. The indication must fall within the specified limits. Settings and readings are to be estimated to the nearest 1% of full screen.

Original Limits Setting (% FSH)	Change in Gain Control (dB)	Indication (%FSH)
80%	-6 dB	32-48%
80%	-12 dB	16-24%
40%	+6 dB	64-96%

Figure 5.2. Ratio limits for curved surfaces.



20%	+12 dB	64-90%
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Military Standards

Military standards tend to use highly specific instructions as part of their requirements, including the design and use of calibration blocks, methods of system performance analysis, and other operating instructions. Included below are excerpts from MIL-STD-2154 which is intended to standardize the process for applying ultrasonic inspection in the evaluation of wrought metals and their products greater than 0.25 in. thick. It is applicable to the inspection of forgings, rolled billets or plate, extruded or rolled bars, extruded

or rolled shapes, and parts made from them. It does not address non-metals, welds, castings or sandwich structures.

It addresses both immersion (type I) and contact (type II) methods of inspection of wrought aluminum (7075-T6, 2024), magnesium (7.K60A), titanium (Ti-6Al-4V annealed) and low alloy steel products (4130, 4330, 4340), using five classes of acceptance.

(Excerpts Taken from MIL-STD-2154)

Inspection, Ultrasonic, Wrought Metals, Process for

1. SCOPE

Detection of flaws in wrought metals having cross section thickness equal to 0.25 In. or greater.

4. GENERAL REQUIREMENTS

Orders shall specify type of inspection and quality class in drawings including identification of directions of maximum stresses.

Personnel shall be Level II or better, MIL-STD-410. Level I Special permitted per 410.

Detailed procedure to be prepared for each part and type of inspection. It shall cover all of the specific information required to set-up and perform the test, i.e., (a), (b), (c),... (o), (p), (q).

5. DETAIL REQUIREMENTS

5.1 Materials_

Couplants

- Immersion (Type 1), free of visible air bubbles, use preapproved additives i.e. inhibitors, wetting agents
- Contact (Type II), viscosity and surface wetting sufficient to maintain good energy transmission. Standard Test Block Materials - listed alloys or from the same alloy as the part, free from spurious indications. To be tested to class AA using Immersion, L-wave.

5.2 Equipment.

Frequency: 2.25 - 10 MHz, Ref: ASTM E317

Gain: - 5% FSH over full range

Alarm: Front surface synchronization

Transducers

- L-wave, 3/8 - 3/4 in. dia.
- S-wave, 1/4 - 1 in. dia. or length

Manipulators

- Angular adjustment - ± 1 degree
- Linear accuracy - ± 0.1 in.

5.3 Reference standards.

Flat surface - #2,3,5,8 FBH per E-127

Curved surface - $R < 4$ in., special block

Angle Beam - 11W, for transducer exit/angle

SDH block, rectangular beam hollow cylinder block, pipes

Verification - drawings/radiographs, comparison amplitude plots, linearity plots, surface finish, material certs.

5.4 Inspection procedures.

Scan parallel to grain flow up to speeds that found reflectors in base materials and at reference amplitude, angulate to maximize, check high stress regions

Near surface resolution limit for 2:1 SIN

- 118 in. for 1 in. range thru
- 1/2 in. for 15 in. range
- failure = test from both sides

Immersion -

Water path $\pm 1/4$ in. of standardization, maximize water-metal interface signal, develop DAC if needed,

angle transducer $23^\circ \pm 4$ to get S-wave from 45-70 degrees in aluminum, steel and Ti. Set primary reference response at 80% FSH. Set scan index at between 50 and 80% of the half-amplitude response distance from reference standard. Establish for each transducer used. Establish transfer factor using 4 points from different locations based on back surface reflections or notches, but only if the response is more or less than the comparable signal from the reference standard, allowable range between 60 and 160 percent or ± 4 dB.

Acceptance Criteria

Discontinuities are evaluated with gain set for 80% FSH on a test block with hole diameter equal to the smallest acceptable for the applicable class and with a metal travel distance equal to the reflector *depth within* $\pm 10\%$.

Acceptance Criteria Matrix

Quality Class	Single (#FBH)	(#FBH°)	Multiple	Linear (inch)
AAA	#1	#3	10% or	1/8
AA	#3	#2	-	1/2
A	#5	#3	-	1
B	#8	#5	-	1
C	#8	----- NA -----		
° Two or more less than 1 inch apart				

For L-wave inspections, loss of back reflection exceeding 50 percent shall be cause for rejection unless due to non-parallelism or surface roughness.

Linear discontinuity length is measured using the 50% drop method.

5.5 Quality assurance provisions.

System performance to be checked prior to, at 2 hour intervals during continuous testing, at instrument setting changes or modules, and after testing. DAC setups are to be checked *daily* for the thickness range of material being inspected.

Data records shall be kept on file in accordance with contract/order. Location and general shape (*size*) of rejectable indications are to be recorded. Indications in excess of acceptance criteria are permitted if they will be subsequently removed by machining. A C-scan shall be made that shows the location and size (by discontinuity grade) with respect to the material being scanned.

Building Codes

Nondestructive testing requirements are often melded into the detailed requirements associated with the construction of welded structures stressed with static loads (buildings), dynamic loads (bridges), or tubular structures. Different sets of acceptance criteria are used based on the intended purpose of the structure. The base metals involved are mostly carbon and low alloy steels, commonly found in the fabrication of steel structures.

The wording and approaches included on the next pages use typical criteria based upon static loads. Included are those for scanning levels (which change with sound path) and bases for rejection depending upon flaw class.

The flaw severity class is determined by the degree to which the flaw indication exceeds the reference level, as modified by sound path attenuation, and the weld

thickness and search unit angle. The classes and reject criteria are as following:

Class A (large) -All are rejectable

Class B (medium) -Reject if longer than 3/4 in.

Class C (small) -Reject if longer than 2 in.

Class D (minor) -All are acceptable

The presence of more than one class in close proximity are addressed in special notes, as are the treatment of primary tensile stress welds and electro slag welds.

(Excerpts Taken from a Representative Building Code)

1. INSPECTION

Personnel Qualification

Personnel performing nondestructive testing other than visual shall be qualified in accordance with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1 A. Only individuals qualified for NDT Level I and working under the NDT Level II or individuals qualified for NDT Level II may perform nondestructive testing.

Extent of Testing

Information furnished to the bidders shall clearly identify the extent of nondestructive testing (types, categories, or location) of welds to be tested.

ULTRASONIC TESTING OF GROOVE WELDS

General

The procedures and standards described below are to be used in the ultrasonic testing of groove welds and heat-affected *Tones between the* thicknesses of 5/16 in. (8.0 mm) and 8 in. (203 mm) inclusive, when such testing is required. These procedures and standards are not to be used for testing tube-to-tube connections.

Variation in testing procedure, equipment, and acceptance standards may be used upon agreement with the Engineer....

Ultrasonic Equipment

1-6 MHz, Pulse-Echo
Horizontal Linearity- 2%
Stability - .-1 dB for 15% voltage change
Gain - 60 dB. +1 dB

Transducers

L-wave, 112Area>1
2-2.5 MHz
resolve 3-hole S-wave. (5/8-1) x (5/8-13116)
ratio:1.2:1
angle: ± 2 degrees (70, 60, 45)
clearance: 1 in.

Reference Standards IIW

Block+ portables
Resolution Block
Qualification Frequency Horiz lin - 40 hrs.
Gain - two months Probe
Noise - 40 hrs. Shoes &
Angles - 8 hrs.

6.18 Calibration for Testing

Sensitivity/Sweep

Prior to test at location
30 Minute intervals
Changes in personnel, equipment or electrical disturbances
Zero Reference Level
Gain setting © 80% FSH from 0.06 in. SDH

Testing Procedures

Positional Layout X, Y
Surface condition clear
Lamination check- L-wave

All butt joint welds shall be tested from each side of the weld axis.... It is intended that, as a minimum, all welds be tested by passing sound through the entire volume of the weld and the heat-affected zone in two crossing directions, wherever practical.

Table B-1 Ultrasonic Acceptance-Rejection Criteria

	Weld Thickness* in in. (nun) and Search Unit Angle										
Discontinuity Severity Class	5/16(8) thru ¾ (19)	>¾ thru 1½ (38)	>1-1/2 thru 2 ½ (64)			>2 ½ thru 4 (100)			>4 thru 8(200)		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 & lower	+2 & lower	-2 & lower	+1 & lower	+3 & lower	-5 & lower	-2 & lower	0 & lower	-7 & lower	-4 & lower	-1 & lower
Class B	+6	+3	-1 0	+2 +3	+4 +5	-4 -3	-1 0	+1 +2	-6 -5	-3 -2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	-2 to +2	+1 +2	+3 +4	-4 to +2	-1 to +2	+2 +3
Class D	+8& up	+5& up	+3& up	+6& up	+8& up	+3& up	+3& up	+5& up	+3& up	+3& tip	+4& up

Evaluation - Set signal from indication at 80% **FSH**. Difference between "indication Level" setting and "Zero Reference Level" setting is measure of severity. For sound paths over 1 in., attenuation compensation (2 Db/in. over 1 in.) is used.

"Indication Rating" =

Indication Level - Zero Reference Level - Attenuation

Each weld discontinuity shall be accepted or rejected on the basis of its indication rating and its length.

Notes:

1. Where possible, all examinations shall be made in Leg I unless otherwise specified. Examinations in Leg II or III shall be made only to satisfy provisions of this table or when necessary to test weld areas made inaccessible by an unground weld surface, or interference with other portions of the weldment.

2. Whenever indications occur at the weld metal/base metal interface, *they* shall be further evaluated with 45, 60, or 70 degree transducers, whichever sound path is nearest to being perpendicular to the suspected fusion surface.

3. B is the material surface opposite to the surface from which the initial scanning is done.

Table B-2 Scanning Levels

Sound path* in in. (mm)	Above Zero Reference, dB
through 2-1/2 (64mm)	14
>2-1/2 through 5 (64-127 mm)	19
>5 through 10 (127-254 mm)	29
>10 through 15 (254-381 mm)	29

**This column refers to sound path distance; NOT material thickness

Table B-3 Procedure Legend

Material Thickness (inches)	Top Quarter	Middle Half	Bottom Quarter	Procedure Number
5/16 to 1/4	70°	70°	70°	# 1
1/4 to 1/2	60°	70°	70°	# 4
1/2 to 3/4	45°	70°	70°	# 5
3/4 to 1	60°B	70°	60°	# 7
1 to 1 1/2	60°B	60°	60°	#10
1 1/2 to 2	45°B	70°	45°	#11
2 to 3	45°B	45°	45°	#13

Chapter 5 Review Questions

O.5-1 A governing specification calls for shear wave, angle beam examination of the component.

What angle should be used?

- A. 45 degrees when inspecting a thick, 45-degree preparation weldment
- B. 60 degrees when inspecting a 1 in. thick weldment
- C. both A and B
- D. the angles permitted by procedure qualification

Q.5-2 Accept/reject criteria may be specified in a code, specification, or the procedure. Upon what should these accept/reject levels be based?

- A. accept/reject criteria should be based upon the experience of the operator
- B. upon the item's end use and the critical flaw size
- C. minimum size that can be detected
- D. upon the largest size that can be detected

Q.5-3 What is the critical flaw size in a forging to be used in an aircraft landing gear?

- A. 0.200 in. long
- B. 2 mm long by 3 mm wide
- C. a flaw that will grow during service
- D. a flaw which may cause failure during service

Q.5-4 A set of curves of amplitude versus area were developed for examination of a steel forging. A reflector was found which was determined to be larger in extent than the sound beam diameter. Which criterion, of those given below, should be used to size the reflector?

- A. directly compare the amplitudes and select the site giving the same amplitude
- B. multiply the reflector amplitude by 1.36 and select the equivalent size from the curves
- C. move the search unit in orthogonal directions until the amplitude drops to 50 percent of maximum to establish the boundaries of the reflector
- D. multiply the sound beam diameter by 1.36 to yield the reflector size

The Following Questions Apply to ASTM A 609

Q.5-5 Reference standards are to be constructed from materials that _____

- A. come from the same heat as the test parts
- B. represent the alloy and heat treatment of each part
- C. have been L-wave tested to assure freedom from major flaws
- D. have a similar metallurgical structure

Q.5-6 Personnel conducting UT shall be certified in accordance with _____

- A. SNT-TC-1 A
- B. the manufacturer's written practice (procedure)
- C. the buyer's written practice (procedure)
- D. nothing, they do not have to be certified

Q.5-7 Reference blocks are to be made using FBHs _____

- A. ranging in size from 3164 - 8164 in.
- B. of a single size equal to 114 in.

- C. at depths covering the range from 1-8 in.
- D. none of the above

Q.5-8 Scanning practices call for transducer positions to. _____

- A. be from two orthogonal directions
- B. overlap each other by 10 percent
- C. change at rates at least equal to 6 in./sec
- D. none of the above

Q.5-9 The ARL is to be set on the screen such that _____

- A. the peak signal amplitude equals 3/4 FSH
- B. surface effects are reflected as a revised ARL
- C. the backwall echo is in the middle third of the sweep
- D. scanning can be done at 6 dB over reference level

Q.5-10 The work order has designated the inspection to be done to a quality level of "4" throughout a disc-shaped casting, 12 in. in diameter and 4 in thick. Which of the observed discontinuities are rejectable?

- A. signal 50 percent above ARL, 2 in. long by 2 in. wide
- B. signal 20 percent above ARL, 2.6 in. in diameter
- C. signal 100 percent ARL, 1.5 in. wide by 3 in. long
- D. signal 90 percent ARL, area of 6.2 in.

Q.5-11 The instrument recalibration schedule calls for the system to be checked (during testing) _____

- A. prior to, every 4 hours, at personnel changes and at testing end

B. every 8 hours per union contract

C. if system performance suggests problems are present, e.g., the battery light starts to flash

D. periodically, using the transfer block as a basic reflector

Q.5-12 A region with loss of back reflection (below 50 percent) has been found; the next step is to _____

- A. inspect the region using another means such as radiography
- B. inspect the region using angle beams from two directions
- C. recheck to assure operational errors were not at fault
- D. list as "questionable area" in final report

The Following Questions Apply to

ASM Section V, Article 5

Q.5-13 Reference standards (calibration blocks) are to be constructed from materials that _____

- A. came, from the same heat as the test parts
- B. have a similar metallurgical structures as the test parts
- C. are the same material specification, grade, and heat treatment as parts
- D. are of the same thickness as the test parts

Q.5-14 Personnel conducting UT shall be certified in accordance with _____

- A. SNT-TC-1A
- B. the referencing Code section
- C. the vendor's written practice
- D. the Code of Ethics for ASME

Q.5-15 The calibration blocks for L-wave testing of castings shall use SDHs as shown in _____

- A. IIW block
- B. Figure 5.1
- C. SA-609
- D. none of the above

Q.5-16 Scanning practices call for transducer positions to _____

- A. be from two orthogonal directions
- B. overlap each other by 10 percent

C. never scan at rates in excess of 6 in./sec

D. none of the above

Q.5-17 A 3.5 in. thick casting, intended for a nuclear application, is being inspected to T-541.4. The quality level is to be assigned:

- A. in cooperation with the buyer as per Par. 2 of SA 609

note: SA 609 is identical to A SIM A 609

B. as level 3, since the thickness is between 2 and 4 in.

C. as level 1. for near surfaces and level 3 for middle 1.5 in.

D. following a formal NRC review for approval

Q.5-18 For a 3.5 in. nuclear grade casting, which of the following indications is (are) considered rejectable?

- A. 1.20% ARL, Depth = 0.75 in, Area = 1.3 in., Length = 1.0 in
- B. 110% ARL, Depth = 1.25 in, Area = 1.8 Length = 2.75 in
- C. 100% ARL, Depth = 2.0 in , Area = 3.1 in. Length = 2.0 in
- D. all of the above

Q.5-19 Compensation for differences between calibration blocks and cast test parts is _____

- A. made by adjusting the reference gain in accordance with back wall reflections
- B. made by adjusting the reference gain using pairs of matched transducers
- C. not allowed
- D. not addressed

QS-20 Several screen height linearity checks yielded the half amplitude results listed below for initial settings of 100, 80, 60, 40, and 20 percent FSH. Which set of readings (%FSH) is considered out of calibration?

- A. 54, 42, 27, 19, 9
- B. 50, 36, 26, 20, 11
- C. 48, 37, 32, 21, 10
- D. 45, 44, 33, 18, 9

**The Following Questions Apply to
the Representative Building Code**

Q.5-21 A check of transducer performance using the IIW block indicated the following angles were being used. Which set(s) is not in compliance with the requirements of the Representative Building Code?

- A. 68, 72, 44, 62
- B. 46, 69, 63, 59
- C. 45, 71, 59, 62
- D. 43, 62, 72, 68

Q.5-22 The signal from a weld discontinuity, set at 80 percent FSH, results in the gain being set at 50 dB. The reference reflector required a gain setting of only 44 dB. The travel path was less than 1 in.. The weld thickness is 2.5 in. and a 45-degree angle beam transducer was used. What is the flaw severity class?

- A. A
- B. B
- C. C
- D. D

Q.5-23 I low long would the indication have to be in order to be considered rejected for the above question?

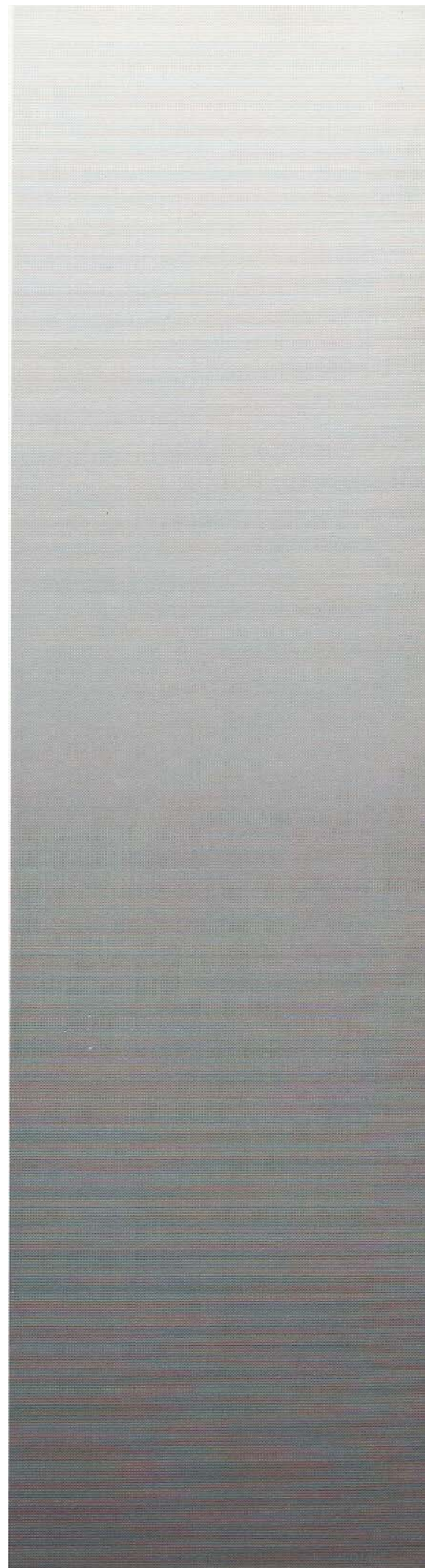
- A. longer than 2 in.
- B. longer than 3/4 in.
- C. any length
- D. it would be acceptable regardless of length

Q.5-24 The transducer in the above problem was being used in accordance with Procedure Number _____

- A. #4
- B. #5
- C. #7
- D. all of the above

Chapter 6

Special Topics



Chapter 6

Special Topics

This section discusses a few items which represent technologies which are not in the mainstream of UT but are of importance in that they represent former application areas of interest and/or emerging issues which will become part of the way UT is performed in the future.

Resonance Testing

The resonance technique is, perhaps, the oldest acoustic/ultrasonic nondestructive testing technique other than the visual method. Metal structures, especially castings and forgings, will audibly ring when struck a sharp blow. An experienced listener could often tell by the ringing tone whether the part was flawed or not. A structure such as a bell when severely flawed sounds wrong to most anyone, experienced or not; however, the accuracy of this technique left much to be desired. With the advent of equipment capable of operating at ultrasonic frequencies, resonance was one of the first techniques used for thickness measurement; although some flaw detection, such as for laminations, was also performed. When a piezoelectric crystal is excited with a voltage varying at the resonant frequency, the mechanical energy produced is greatly increased. This frequency is achieved when the wavelength in the material is twice the thickness or a multiple thereof.

In general use, a transducer is excited by a time-varying frequency designed to sweep the crystal through the fundamental and several harmonic frequencies. When a resonant condition is achieved, it is sensed as an increased loading on the transducer by the electronics and displayed on the readout device. Since the

difference between harmonic frequencies is equal to the fundamental frequency, it does not matter which harmonics are excited.

Resonance testing was commonly used, especially in the basic material industries such as the steel producers, as a quality control measure for both thickness and laminar defects. Improved electronic circuits have been used to create pulse-echo devices which are more accurate and easier to use and interpret. As a result, resonance testing is no longer in common use except for some primary materials characterizations.

Flaw Sizing Techniques

Flaw detection with ultrasonics is at an advanced state of the art. Significant flaws in most structures can be detected. When a UT indication is identified as a flaw, normally some estimate of its size is required. Below is a list of variables which affect these measurements. This list includes, but is not limited to, flaw type, flaw shape, location, multiple flaws in same location, geometric reflectors in same location, grain size and orientation, flaw orientation, part configuration, search unit characteristics, and sound beam characteristics. Each of these variables can affect the measurement to a degree which is not the same from flaw to flaw.

In general, there are two flaw size categories which are usually treated differently, those with flaws larger than the beam diameter and those smaller than the beam diameter. As a result of these factors, no one technique provides accurate flaw sizing on all flaws; however, numerous techniques have been devised for flaw sizing.

Most of these are based on some consideration of signal amplitude.

Flaws can generally be described by three dimensions, length, width, and height, where the length and height are in a plane normal to the direction of maximum stress and the width is in the direction of the stress. In most situations little emphasis is placed on the determination of width since it has little effect on the stress pattern. Length is measured normal to the stress and parallel to the test item surface, while height is measured normal to both the stress and the surface. Of these two, length can ordinarily be measured successfully with the desired accuracy. Height, on the other hand, is much more difficult to measure.

For laminar-type flaws, the length and width refer to the dimensions in a plane parallel to the entry surface. Orientations of these dimensions is a matter of procedure or choice.

Small flaws may be classified into two categories, flaws smaller than the wavelength and flaws larger than the wavelength. A circular disc flaw much smaller than the wave length will reflect a spherical wave with pressure proportional to the third power of the flaw diameter and inversely proportional to the wavelength. Very small flaws reflect very little energy and are difficult to detect.

Flaws larger than the wavelength and less than the beam diameter reflect sound proportionally monotonically with flaw size. That is, as the flaws get larger, the amplitude increases, although not in a linear fashion. Two approaches commonly used include area-amplitude blocks and the Krautkramer DGS (distance-gain-size) diagram. In the first, specimens are prepared with different size reflectors. The amplitude from the flaw is compared directly with the amplitude from a known reflector. When a match is achieved, the flaw is assigned the reflector size.

In the DGS diagram, a series of curves with flaw size as the parameter are plotted on an amplitude-versus-sound-path-diagram. Back surface echo amplitude is plotted on the same

diagram. Flaw amplitudes are then used to assign a flaw size where the equivalent flaw size is a circular disc.

Large flaws are measured by scanning or by time-difference measurements, and, of course, these may be combined. In laminar flaw measurement, the search unit is moved back and forth until the amplitude of the flaw signal drops to a predetermined level. Using this technique, the flaw perimeter can be determined. This technique is usually quite satisfactory.

This method is not the same for angle beam measurements which are usually used in weld examination. Measurement of the throughwall dimension (height) is much more difficult. Several techniques have been developed in relationship to thick-wall weld examination and a few of these will be discussed.

One of the most common techniques is the so called "dB drop" technique. In this technique, the maximum amplitude signal is located and the sound path and location recorded. The search unit is then moved toward the reflector until the signal drops by a preselected amount, usually 6 dB. At this point, the sound path and location are recorded. This step is repeated with movement away from the reflector. Plots of the data using the known refracted angle provide a measure of the height of the reflector.

A similar but slightly different technique is the leading-lagging ray approach. In this, the search unit is maneuvered across a side-drilled hole reflector in a calibration block as in the dB drop technique on a reflector. These data are used to establish the leading and lagging beam edge angles. In the examination, the locations of the search unit are established as in the dB drop technique but the plots are made on the basis of the pre-established beam edge angles.

In the dynamic time of flight technique, a focused, longitudinal wave, angle beam search unit mounted on a mechanical scanner passes the search unit across a crack. The sound path reflection from the crack is recorded with the search unit position. The distance to the tip of the crack is determined by triangulation and the

minimum sound path. This technique shows promise of good accuracy in some applications.

Several techniques rely on the detection of diffracted waves emanating from the tips of a crack. These very low amplitude waves, if detected and identified, can be used to measure the flaw height. In the satellite pulse technique the screen is calibrated in through wall dimension rather than in metal path to the reflector. The distance from the tip-diffracted pulse (satellite) to the corner echo is a direct

measurement of the flaw height. This technique has been successfully applied to measure intergranular stress corrosion cracks in the nuclear electric power industry.

Original examination with tip-diffraction used through-transmission techniques. This technique is still used in selected applications. In this technique, angle beam search units are placed on each side of a crack on the entry *surface*. *These are* manipulated until the peak is maximized and the crack tip is then located by triangulation.

Appendices

Appendix A

A Representative Procedure for Ultrasonic Weld Inspection

1.0 SCOPE:

- 1.1 This procedure is to be used for detecting, locating and evaluating indications within the weld and heat affected zone of carbon steel and low alloy welds using the contact inspection technique,

2.0 PERSONNEL:

- 2.1 Personnel performing this examination shall be qualified in accordance with PQ-1 which is in accordance with the guidelines of SNT-TC-1A (1988). Only Level II or III personnel shall evaluate and report test results.

3.0 REFERENCE:

- 3.1 NE-1 "Nondestructive Testing Equipment", Rev O.

4.0 EQUIPMENT:

- 4.1 Pulse-echo Instruments and Transducers shall be selected only from the equipment inventory which has been qualified and calibrated to meet the requirements of NE-1, Nondestructive Testing Equipment.
- 4.2 The calibration block to be used for production inspection shall be the DSC (Distance/Sensitivity) block.
- 4.3 Couplants may include cellulose gum (mixed with water) or glycerin.

5.0 PROCEDURE:

- 5.1 Review each test item's inspection requirements to be aware of contract stipulations for each weld joint configuration prior to conducting production weld inspection. Select an established Technique Sheet for the weld joint configuration or create a new one that identifies the inspection parameters of transducer angles, applicable segments of the welds) to be examined, maximum beam path and companion longitudinal wave scan region, scan levels, and acceptance criteria in accordance with Form A, shown in Section 10.0 of this procedure. If a new Technique Sheet is prepared by other than the Level III individual, the Technique Sheet shall be reviewed and approved by the Level III prior to use during production inspections.
 - 5.1.1 Using Reference Table B shown in Section 9.0 of this procedure, identify the transducer angle(s) required to totally inspect the material thickness(es) and joint design(s) being considered.
 - 5.1.2 Using the selected angles and material thickness(es), calculate the expected beam

path and range of straight beam coverage required.

- 5.1.3 Using Table C of Scan Levels shown in Section 9.0, identify the scan levels to be used for each segment of the weld.
- 5.1.4 Using Reference Table D, identify the indicating rating levels which correspond to Classes 1 through IV and enter them on Form A.
- 5.1.5 Enter any other special requirements for a specific configuration or job in the comments section of Form A.

5.2 Prepare all applicable surfaces for UT inspection:

- 5.2.1 Clean contact surfaces of weld spatter, dirt, rust, grease and any roughness that will interfere with the free movement of the search unit or would prevent the transmission of ultrasonic vibrations.
- 5.2.2 Smooth weld surfaces adequately to prevent interference with the interpretation of the examination. Weld surfaces shall merge smoothly into the surfaces of the adjacent base metal.

5.3 Verify all equipment qualification and system calibration checks prior to testing:

- 5.3.1 Verify that all equipment to be *used* has been qualified in accordance with NE-1 and the schedule requirements of Table B.

5.4 Conduct and Maintain System Calibration Checks:

- 5.4.1 Conduct the inspection system calibration in accordance with NE-1, being sure that the reject control is turned off and remains off throughout the inspection process.
- 5.4.2 Calibrate the inspection system (instrument, cable and transducer) before first use and
 - a. Every sixty minutes,
 - b. At the completion of each examination or series of similar examinations,
 - c. When examination personnel change, and
 - d. When electrical circuitry is disturbed in any way, e.g., changes in transducer, battery, electrical outlet, co-axial cable or power outage.
- 5.4.3 Straight Beam Calibration
 - a. Using a location on the base metal free of any indications, set sweep range to clearly display both the first and second back surface reflections.
 - b. Set the pulse reflected from the first back surface to a height of 80% FSH.

Table A. Schedule of Equipment Qualification

Check	Transducers* Angle	Instrument
Before First Use	Resolution Dimensions Approach Distribution Index Point Sound Path Angle Internal Reflection	Horizontal linearity Vertical Linearity
After 4 hours of use	Index Point Sound Path Angle	
After 80 hours use	Internal Reflection	Horizontal Linearity Vertical Linearity

* Straight Beam Transducers are to be checked for resolution before first use.

5.4.4 Angle Beam Calibration

- a. Using the DSC block, adjust the instrument to represent the actual sound path distance using either the 5 in. or 10 in. range on the CRT screen,
- b. Using the DSC block, adjust the maximum attainable signal from the 0.06 in. SDH to 50% of FSH1 and record the "Reference Level" reading of the gain control, on Form B, "Ultrasonic Inspection Results."

5.5 Base Material Examination:

- 5.5.1 Using a calibrated 2.25 MHz longitudinal transducer over the area identified in the Technique Sheet, scan the base material through which angle beam testing will take place using a 20% overlapping pattern and at a speed not to exceed 6 in. per second. This initial base material examination is for the purpose of assuring a predictable environment for the angle beam testing that is to follow and is not to be used as an acceptance/rejection examination.
- 5.5.2 If any area of the inspected base metal exhibits total loss of back reflection or any indication equal to or greater than the original back-reflection height, its size, location and depth shall be reported on the Form B, shown in Section 10.0
 - a. Size is to be determined using the 50% amplitude loss (6 dB) method for discontinuities larger than the transducer.
 - b. Size is to be determined using the transducer edge approach method for discontinuities smaller than the transducer.
 - c. Unsatisfactory regions are to be identified using the shaded areas in Form B and columns X, Y, Depth, Length, and Comment.
 - d. Satisfactory base metal tests results are to be indicated for each weld by placing a check mark in the column identified "L-wave" in Form B.

6.0 WELD AND HAZ EXAMINATION USING ANGLE BEAM TRANSDUCERS:

- 6.1 Using the 2.25 MHz angle beam transducer identified in the technique sheet and operating at a scanning level about the 0.06 in. SDH reference level in accordance with the technique sheet, scan the entire volume of the weld and HAZ (a) using a 30% overlapping pattern, (b) while continuously rotating the transducer a few degrees alternately to each side and (c) at a speed not to exceed 6 in. per second. Enter all applicable information onto "Ultrasonic Inspection Results," Form B, as each item in the form is identified. For butt welds, repeat the scan from the opposite side of the weld.
 - 6.1.1 Repeat 6.1 for all required examination angles as identified in the technique sheet.
 - 6.1.2 if part of the weld is inaccessible for examination due to base material laminar content or restrictive geometric conditions, full weld coverage shall be attained using one or more of the following alternatives.
 - a. Grind the weld surfaces) flush and scan on the weld surface.
 - b. Scan from other accessible surfaces.
 - c. Use other search unit angles such as 45°, 60°, or 70°.
- 6.2 Evaluation of Discontinuities
 - 6.2.1 When an indication of a discontinuity appears on the screen, use the gain control (or attenuator) to adjust the maximum attainable indication to 50% of the CRT's FSH. Record the gain control reading (dB) on Form B, "Ultrasonic Inspection Results" shown in Section 10.0, in the "Indication Level" column.
 - 6.2.2 Estimate the effect of sound attenuation by subtracting 2 in. from the sound path distance to the indication and multiply the remainder by 3 (i.e., triple the remainder). Record this value (dB) in the "Indication Factor" column of Form B.
 - 6.2.3 Determine the "Indicating Rating" by subtracting the sum of the "Indication Level" and the

- "Indication Factor" from the "Reference Level" setting and record the result *in the* "Indicating Rating" column of Form B.
- 6.2.4 Evaluate the length of each discontinuity by measuring the distance between the center line of the transducer's 50% drop locations.
- 6.2.5 Classify (I, II, III, IV) each discontinuity in accordance with *the criteria* listed in the Technique Sheet and establish its accept/reject status based on each indication's crass, length, and separation from nearby surfaces and adjacent indications.
- 6.2.6 For each weld that is inspected, the results of that inspection shall be recorded using Form B, however only the weld ID, L-wave check, acceptance status and comments (if any) need be noted *for* those welds *free of* any measurable ultrasonic indications.

7.0 DOCUMENTATION:

- 7.1 Record the detailed test results *of* all inspections *on* Form B, "Ultrasonic Inspection Results," as shown in the attachments.
- 7.2 Mark locations *of* unacceptable indications directly over the discontinuity and note the depth and class of each discontinuity on nearby base metal.

8.0 REPAIRS:

- 8.1 After weld *repairs have* been made, *re-examine* repaired areas in accordance with this procedure and enter results on the interlaced lines of Form B.

9.0 REFERENCE TABLES: (See Tables B, C, and D)

10.0 ATTACHMENTS AND SAMPLE FORMS: (See Forms A and B)

Table B. Testing Angle Selection

Material Thickness (inches)	Angles of Inspection		
	Top	Middle	Bottom
0.30 - 1.50	70	70	70
>1.50-1.75	70	70	70
>1.75-2.50	60	70	70
>2.50-3.50	45	70	70
>3.50-4.50	60	70	60
>4.50-5.00	60	60	60
>5.00-6.50	45	70	45
>6.50-7.00	45	45	45

General Notes:

1. The "Top" of the weld extends one-quarter through the thickness of the base material and is the region closest to the surface from which the angle-beam scanning takes place. The "Bottom" of the weld is the quarter-thickness region opposite from the scan surface. The "Middle" zone is the central region of the weld and is equal to one-half of the thickness of the base material.
2. Inspections should be made in first leg of beam path. .
3. Legs II and III can be used when access is limited.
4. All fusion-line indications shall be further evaluated with transducers which exhibit beam paths nearest to being perpendicular to the suspected fusion surface.

Table C. Ultrasonic Scanning Levels

Sound Path (in.)	Above Zero Reference dB
thru 2½	12
>2½ to 5	19
>5 to 10	29
>10 to 15	39

Table D. Ultrasonic Accept-Reject Criteria

Weld Thickness (inches)	Class				Angle
	*	IT	III	N**	
0.30-0.75	+5	+6	+7	+8	70°
>0.75-1.50	+2	+3	+4	+5	70°
>1.50-2.50	+1	+2 & +3	+4 & +5	+6	60°
	-2	-1 & 0	+1 & +2	+3	70°
>2.50-4.00	0	+1 & +2	+3 & +4	+5	45°
	-2	-1 & 0	+1 & +2	+3	60°
	-5	-4 & -3	-2 to +2	+3	70°
>4.00-8.00	-1	0 & +1	+2 & +3	+4	45°
	-4	-3 & -2	-1 to +2	+3	60°
	-7	-6 & -5	-4 to +2	+3	70°

* and below

** and above

General Notes:

1. Class II and III indications shall be separated by at least 2L, L being the length of the longer flaw
2. Class II and III indications shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the indication length
3. Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined.
4. Rejectable are all Class I indications, Class II indications in excess of 0-60 in., and Class III indications over 1.25 in. All Class IV indications are considered acceptable

Form A. Ultrasonic Testing Technique Sheet

REF NUMBER: TS-W-

DATE: _____

APPROVED: _____
Level **III**

Applicable 1oint(s)

Thickness: _____ - _____

Transducer Angles:

TOP: _____

MID:

BUT:

Sketch of Inspection Scheme

L-wave Range: _____

Scan Level: _____

Rating/Class/Reject Criteria:

db /I/All

_____db / II I.>0.60 inch

_____ db / III / L>1.25 inch (M)

____db / IV / Accept

COMMENTS:

Prepared By:

Level	I	II	III
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FORM: UT-TS 1, 8/89

Form B. Ultrasonic Inspection Results Form[illegible]

Review Questions for a Representative Procedure for Ultrasonic Weld Inspection

Q-A1 With scanning being done from the top surface of a 1-1/4 in. thick weldment, the scanning level for inspection of the root area would be, with respect to the reference level,

- A. 12 dB
- B. 14 dB
- C. 19 dB
- D. 29 dB

Q-A2 The reference level recorded using the DSC block was 32 dB. An indication detected near the root of the weld was 34 dB when corrected for attenuation. *Thus* the indication is to be designated as being _____

- A. Class I
- B. Class II
- C. Class III
- D. Class IV

Q-A3 The weld joint being inspected has a backing bar near the 1/4 in. root with a 45-degree groove angle and unground weld crown. Having found an indication at a depth equal to 1/2 the thickness of the base material and in the vicinity of the interface between the base metal and the weld metal, further investigations should be conducted using _____

- A. an L-wave transducer to assure the base material is free of laminations or any other sound reflecting conditions
- B. the same angle beam transducer that detected the indication, only scanning from the opposite side of the weld
- C. a 45-degree angle beam transducer and a beam path within the first leg of the Vee path
- D. a 45-degree angle beam transducer and a beam path within the second leg of the Vee path

Q-A4 A Class II indication in a weld that is in a region which is carrying a primary tensile stress has been found to be 0.45 in. from the end of the 0.75 in. thick weld and within 0.35 in. of another indication that has been determined to be 1.25 in. long. The Class II indication has been determined to be 0.15 in. long. The status of the weld

should be identified as _____

- A. acceptable, based on proximity to the next nearest indication
- B. acceptable, based on indication-length-to-weld-thickness ratio
- C. rejectable, based on proximity to the end of the weld
- D. rejectable, based on proximity to the next nearest indication

Q-A5 A Class III indication found at a fusion interface in a weld that is in a region which is carrying a primary tensile stress is 1 in. from the end of the 0.75 in. thick weld and within 0.5 in. of another indication that has been determined to be 0.2 in. long. The Class III indication has been determined to be 0.5 in. long. The status of the weld should be identified as _____

- A. acceptable, based on proximity to the next nearest indication
- B. acceptable, *based on* the indication being at a fusion interface but less than 1.25 in.
- C. rejectable, based on proximity to the next nearest indication
- D. rejectable, based on proximity to the end of the weld

Q-A6 An indication in the top quarter of a 3 in. thick weld has been examined using three different angle beam transducers (45, 60, and 70 degree), each of which has resulted in a rating equivalent to the initial reference level. The indication should be identified as _____

- A. Class I
- B. Class II
- C. Class III
- D. Class IV

Q-A7 The procedure calls for compensating for attenuation effects through [the use of correction factors which, upon examination, appear to be based upon _____

- A. an effective near field that does not exceed 2 in.
- B. an effective beam spread and/or scatter that is at a rate of 3 dB per in. beyond the near field

- C. both A and B
- D. the changes in ultrasonic wave energy scatter caused by changes in allowable operating frequencies

Q-A8 A transition butt weld is to be examined in accordance with the procedure. The weld is to be a smooth transition from a 3.75 in. thick base material to a 3.25 in. thick material. The procedure calls for the weld to be examined using

- A. a 70-degree transducer from both sides
- B. a 45-degree transducer from both sides
- C. a 60-degree transducer from both sides
- D. all of the above

Q-A9 Inspections conducted in accordance with the procedure are based on contact testing using _____ as a couplant.

- A. water bubblers and similar water-based scanning devices
- B. water and cellulose gum mixtures adjusted for surface conditions
- C. industrial grade oils and greases adjusted for surface conditions
- D. commercial mixtures of proprietary fluids designed to reduce residues prone to cause corrosion in carbon steel

Q-A10 When using a 70-degree transducer to examine the root area of a single Vee weld, the scanning level must be increased by 7 dB over the thin materials scanning level (12 dB) for base metals with thicknesses between _____

- A. 0.50 and 1.00 in.
- B. 0.75 and 1.53 in.
- C. 0.85 and 1.71 in.
- D. 0.95 and 2.25 in.

Q-A 11 The scanning level for use with a 60-degree transducer is set for 29 dB above the reference level established during the system calibration. This scanning level is thus applicable to material thicknesses in the range from

- A. 2.50-5.00 in.
- B. 5.00 - 10.00 in.
- C. 3.54 - 7.08 in.
- D. 4.00 - 8.00 in.

Q-A 12 In preparing for the angle beam inspection, a longitudinal wave scan of the base metal is conducted throughout a region extending at least _____ to either side of the weld center line when a 1 in. welded plate is to be inspected.

- A. 1 in.
- B. 1.71 in.
- C. 2.25 in.
- D. 2.75 in.

Q-A13 Sound path angle and index (exit) point need to be checked every _____

- A. 4 hours of use
- B. 60 minutes
- C. when examination personnel change
- D. at the completion of each series of similar examinations

Q-A 14 Longitudinal wave testing conducted for the purpose of accepting base materials prior to angle beam testing for weld discontinuities, requires an overlap scan pattern of at least

- A. 10 percent
- B. 15 percent
- C. 20 percent
- D. none of the above

Q-A 15 Laminar types of discontinuities are to be recorded on Form B (the "Ultrasonic Inspection Results" sheet) provided they exhibit a pulse height equal to or greater than _____

- A. 50% PSII
- B. 75% FSH
- C. 80% FS 1 I
- D. 90% F¹SH

Q-A 16 Angle beam testing conducted for the purpose of detecting discontinuities within welds and their adjacent heat-affected zones requires an overlap scan pattern of at least _____

- A. 10 percent
- B. 15 percent
- C. 20 percent
- D. 30 percent

Q-A17 If part of the weld is inaccessible for examination due to base material laminar content or restrictive geometric conditions, the best alternative and permitted approach to testing a weld is to _____

- A. scan the weld using search unit angles other than that initially selected, such as 55 or 65 degrees
- B. examine the weld from other accessible surfaces using the magnetic particle method and using the yoke or prod techniques
- C. grind the weld surface(s) flush and scan on the weld surface using the longitudinal wave technique
- D. none of the above

Q-A 1 X An indication is found at a sound path distance of 5.6 in. Thus the effect of sound attenuation to be entered into Form B is estimated to be _____

- A. 8 dB
- B. 9 dB
- C. 10 dB
- D. 11 dB

Q-A19 A series of welds are examined and found to be free of any objectionable indications. Thus,

- A. Form B need not be filled out in its entirety
- B. the status of each weld needs to be marked as acceptable
- C. the indication of satisfactory L-wave inspection *needs* to be marked with a check mark
- D. all of the above

Q-A2() A series of welds are examined and found to contain several objectionable indications. Thus, _____

- A. each objectionable weld needs to be marked with a check mark at the end of each weld loaded in tension
- B. each objectionable indication location needs to be marked directly over the discontinuity
- C. location and depth/class of each discontinuity need to be marked directly over the discontinuity and nearby on the base material, respectively
- D. Form B, completed in compliance with the procedure, is the full documentation required for each indication

Q-A21 In reviewing a completed Form B, it is found that two complete sets of discontinuity

data are recorded for a reflector found at the same location and depth in the same weld. The second set of data is recorded on the line directly below the first set of data. Both sets indicate an unacceptable condition. It is evident that _____

- A. a repair has *been* completed and the repair has been judged to be unacceptable
- B. the inspector misread the data taken during the inspection
- C. a repair is in process and the data will be changed pending the inspection of the repaired region
- D. none of the above

Q-A22 An indication in a 3 in. weldment yields an indication level of +1 dB for the 45-degree transducer and -2 dB for the 70-degree transducer. The indication should be identified as

- A. Class I
- B. Class II
- C. Class III
- D. Class IV

Q-A23 An indication in the middle of a 5 in. weldment has been identified Class III with a 6 dB down length of 1.1 in. This indication, in accordance with the procedure, is _____

- A. considered acceptable
- B. considered rejectable
- C. to be considered for further examination by other NDT means
- D. none of the above

Q-A24 An indication 1.75 in. long and in the vicinity of the base-metal to weld-metal fusion line of a 5 in. weldment has been tentatively identified as Class IV using a single angle beam transducer. This indication, in accordance with the procedure, is _____

- A. considered acceptable since all Class IV indications are considered acceptable
- B. considered rejectable since it exceeds the 1.25 in. limit for fusion type flaws
- C. to be considered for further examination by transducers with angles closest to being perpendicular to the fusion line
- D. To be subjected to X-ray examination in order to obtain a second "technical" opinion.

Appendix B

List of Materials, Velocities, and Impedances

Material	Velocity		Longitudinal Acoustic Z	Wavelength ³	Density ⁴
	V _l	V _r			
Metals					
Aluminum 2SC)	6.35	3.10	17.2	0.635	2.71
Aluminum 17SI	6.25	3.10	17.5	0.625	2.80
Beryllium	12.80	8.71	23.3	1.28	1.82
Brass (naval)	4.43	2.12	36.1	0.443	8.1
Bronze, phosphor (5%)	3.53	2.23	31.2	0.353	8.86
Copper	4.66	2.26	41.8	0.466	8.9
Lead, pure	2.16	0.70	24.6	0.216	11.4
Lead, Antimony (6%)	2.16	0.81	23.6	0.216	10.90
Magnesium	5.79	.10	10.1	0.579	1.74
Mercury	1.42	--	18.5	0.142	13.00
Molybdenum	6.29	3.35	63.5	0.629	10.09
Nickel	5.63	2.96	49.5	0.563	8.8
Incone/ ® (wrought)	7.82	3.02	64.5	0.782	8.25
Monel ® (wrought)	6.02	2.72	53.1	0.602	8.83
Silver Nickel (18%)	4.62	2.32	40.3	0.462	8.75
Steel	5.85	3.23	45.6	0.585	7.8
Stainless Steel 302	5.66	3.12	45.5	0.566	8.03
Stainless Steel 410	7.39	2.99	56.7	0.739	7.67
Titanium (Ti 150A)	6.10	3.12	27.7	0.610	4.54
Tungsten	5.18	2.87	99.8	0.518	19.25
Nonmetals					
Acrylic resin	2.67	1.12	3.2	0.264	1.18
Air	0.33	--	0.00033	0.033	0.001
Fused quartz	5.93	3.75	13.0	0.593	2.20
Ice	3.98	1.99	4.0	0.398	1
Oil (transformer)	1.38		1.27	0.138	0.92
Plate glass	5.77	3.43	14.5	0.577	2.51
Pyrex ®	5.57	3.44	12.4	0.557	2.23
Quartz (natural)	5.73		15.2	0.573	2.65
Water	1.49	--	1.49	0.149	1.00

1. Meters per second x 10³
2. Kilograms per square meter•second x 10⁶
3. Millimeters for longitudinal wave at 10 MHz
4. Kilograms per cubic meter x 10

Appendix C **Answer Key to Chapter Review Questions**

Chapter 1	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Appendix A
1.D	1.C	1.D	1.A	1.D	A1. A
2.C	2. C	2.B	2. C	2. B	A2.A
3. B	3. D	3.B	3.1)	3. C	A3.D
4. A	4. A	4.D	4. C	4.C	A4. D
5.C	5.D	5.D	5.D	5.D	A5. C
6.C	6.D	6.D	6. C	6.D	A6. A
7.C	7. A	7.B	7.A	7.B	A7. C
8. D	8. B	8. B	8.B	8.D	A8.D
9. B	9. A	9. A	9.A	9.A	A9. B
10. B	10. A	1{]. I)	10. D	10. B	A10. C
1 1. A	11.D	11.C	11. A	11. D	All. A
12. B	12. C	12.C	12. B	12. C	A12. D
13.D	13.B	13. D	13. A	13.C	A13. A
14. B	14.C	14.A	14. D	14. B	A14. C
15. A	15.C	15. D	.15.C	15. D	A15. C
16.D	16. A	16. D	16. A	16. B	A16. D
]7. A	17.B	17. B	17. B	17.C	A17. D
18. A	18.B	18.C	18. B	18. D	A18. D
19. C	19.C	19.13		19. C	A19. D
20. A	20.A	20. A		20. B	A20. C
21. B	21. A	21. D		21. B	A21. A
22. B	22. A	22. B		22. C	A22. B
23. D	23. B	23.C		23. A	A23. A
24. D	24. A	24. A		24. B	A24. C
		25. B			
		26. B			
		27. C			
		28. C			

Appendix D References

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