MILITARY HANDBOOK

ULTRASONIC TESTING

NO DELIVERABLE DATA REQUIRED BY THIS DOCUMENT

AMSC N/A

AREA NDTI

DISTRIBUTION STATEMENT A Approved for Public Release; Distribution Unlimited.

MIL-HDBK-728/6

TABLE OF CONTENTS - CHAPTER 6

MIL-HDBK-728/6

6.0 SAFETY NOTICE

Ultrasonic testing involves electrical equipment. Standard laboratory safety procedures for the handling of electrical equipment should be employed in ultrasonic testing. In many facilities, where automated scanning devices exist, caution must be exercised with respect to moving machinery, rotating gears and/or drive belts. Additional safety comments are presented in Section 6.8.

THIS PAGE INTENTIONALLY LEFT BLANK

6.1 INTRODUCTION

Ultrasonic testing employs high-frequency mechanical waves to detect various material variables. These variables can be surface or internal variables, and their locations and/or geometries can be reasonably delineated.

Ultrasonic testing is unique in several areas. Ultrasonics and radiography provide deep, internal inspection capabilities. Normally ultrasonics provides the deepest penetration. (The penetration of X-rays in steel is measured in inches, ultrasonic beams can penetrate twenty feet or more.) Ultrasonics does not require an intrusion of a foreign substance into a material, such as high energy photons of an X-ray beam, but it consists of simple movements of the internal atoms already there. Therefore, ultrasonics can be considered to be the safest of all the inspection methods and is especially adaptable for medical use. Ultrasonic testing has very few restrictions on the kinds of materials it can inspect. The materials do not have to be magnetic (as they must be for magnetic particle testing), they do not have to be electrically conductive (as for eddy current testing), and they do not have to exhibit an adhesive affinity for a liquid (as required for liquid penetrant testing). They do not even have to be a solid. Any volumetrically elastic material can be inspected by this method.

Ultrasonic testing can involve a wide variety of variables. Material variables relating to flaws, voids, inclusions, bonding, thicknesses, and densities can almost always be effectively inspected by ultrasonics. Therefore, ultrasonics is one of the basic nondestructive test methods.

This chapter provides the fundamental principles and guides associated with ultrasonic testing. It includes the theory of operation, the type of equipment, the advantages and disadvantages of the method, various applications and standards, and guides for specific disciplines. The information contained in Chapter 1 should be included with this chapter for general guidelines to the employment of all NDT methods and for a more complete understanding of ultrasonic testing as it compares with other basic methods.

THIS PAGE INTENTIONALLY LEFT BLANK

6.2 BASIC PRINCIPLES

Ultrasonic testing requires the generation of high-frequency mechanical waves
which are usually directed as beams to interact with various property
variables of a material or specimen. The interactions of these mechanical
waves result in the attenuation of the original waves and/or in returned
reflections. The detection of these waves after interactions or reflections
after these interactions produces information relatable to the variables. A
study of the basic principles of ultrasonic testing must therefore include the
means of generating high-frequency mechanical waves, the characteristics of
these waves, how they can be directed, how they interact with material
variables, how they are ultimately detected, the information they contain, and
how the information is displayed.

6.2.1   MECHANICAL WAVES

All materials that hold a natural shape (or a constant density) do so because
their atoms (or molecules) are held in mutual balance between attractive and
repulsive forces. These forces are "short range" forces and only extend
between atoms that are reasonably close together. In this state of balance,
any relative displacement of an atom will cause these forces to change in such
a way that the displaced atom will tend to return to its original position.
At the same time, the displacement of any atom will cause a change in the
force balance seen by all the nearby atoms. Although this change in the force
balance is seen almost instantaneously by the surrounding atoms, due to their
inertia a finite period of time is required for the surrounding atoms to fully
respond to this unbalance. Eventually, however, the atoms experience their
own displacement due to the displacement of the original atom. In this way, a
disturbance at one point can progress to another point and can eventually
progress throughout the material.

There are several kinds of disturbances that can be generated. For those
disturbances that are small and are in what is called the elastic range, the
disturbances are wave-like in nature. These waves have a velocity that is
determined by the characteristics of the material (the magnitude of the
interatomic force gradients and the inertia of their atoms, etc.). Besides
this velocity, frequency and wavelength can be associated with these waves.
Also associated with these waves is amplitude, either as a relative
displacement measurement (the distance the atoms are moved from their balance
points), or as a pressure (relating to the unbalanced forces being generated
between the displaced atoms), or as an energy function (the energy associated
with the atom's potential energy due to their displacements or the kinetic
energy due to their motions, each of these having equal maximum magnitudes).
It is these elastic disturbances that are used in ultrasonic testing.
Equations 1 through 8 show some of the basic relationships between velocity,
frequency, and wavelength, and between time, position, displacements,
pressures, and energies.

$$V = f \lambda \tag{1}$$

where

V = velocity of a wave (cm/sec),

f = frequency of the wave (Hertz, or cycles/sec),

λ = wavelength (cm).

and

$$A(t) = A_o \sin (\omega t + K_1) \tag{2}$$

where

$A(t)$ = amplitude of displacement at time, t,

A_o = maximum amplitude, a constant,

ω = radians per unit time (in terms of the frequency, it equals: $2\pi f$),

K_1 = phase constant that allows for differences in times between the nearest time of zero amplitude and the origin of the time scale.

and

$$A(X) = A_o \sin \frac{2\pi X}{\lambda} + K_2 \tag{3}$$

where

$A(X)$ = amplitude of displacement at position, X,

X = distance along the line of wave travel from a fixed origin,

K_2 = phase constant that allows for differences in positions between the nearest position of zero amplitude and the origin of the position scale.

Equations 2 and 3 can be combined to give:

$$A(X,t) = A_o \sin \frac{2\pi X}{\lambda} - \omega t + K_3 \tag{4}$$

where

$A(X,t)$ = amplitude for any given position, X, and given time, t.

K_3 = phase constant, combined function of K_1 and K_2 above.

The difference in signs between the X and t functions in Equation 4 depends on the direction of the waves. The sign shown is for the case where the wave is moving in the positive X direction.

In Equations 2, 3, and 4, λ or the f in $\dot\omega$ can at any time be expressed in equivalent variables obtained from Equation 1. Also A, the displacement amplitude in Equations 2, 3 and 4, can be replaced with pressure, P, to give:

$$P(t) = P_0 \sin (\omega t + K_1) \tag{5}$$

$$P(X) = P_0 \sin \frac{2\pi X}{\lambda} + K_2 \tag{6}$$

$$P(X,t) = P_0 \sin \frac{2\pi X}{\lambda} - \omega t + K_3 \tag{7}$$

where P_0 is the maximum pressure, a constant, and $P(t)$, $P(X)$, and $P(X,t)$ are pressures as a function of time, t, position, X, or combined position and time, respectively.

It should always be clear that there is a difference between the motion of the atoms that make up the waves and the velocity of the waves. Each atom essentially returns to its place of origin. It is only the energy transferred between atoms that "moves" through the material and determines the wave velocity.

The energy of the waves, normally expressed as intensity, I, or energy per unit time per unit area, can be related to either the maximum displacement amplitude, A_0, or the maximum pressure, P_0:

$$I = \frac{1}{2} \rho V (2\pi f)^2 A_0^2 = \frac{1}{2} \frac{P_0^2}{\rho V} \tag{8}$$

where I is the effective intensity of a beam expressed as energy per unit time per unit area and ρ is the density of the material, mass per unit volume.

The function, ρV, the density times the wave velocity, will be a common function appearing throughout this section and is called the characteristic impedance or the acoustic impedance of the material.

In the elastic range, four main kinds of disturbances or waves can exist: 1) compression, or longitudinal, waves, 2) shear, or transverse, waves, 3) surface, or Rayleigh, waves, and 4) plate, or Lamb, waves. (Other disturbances, e.g., shock waves, bar waves, Love waves, and torsional waves will not be discussed.)

a. Compression or Longitudinal Waves. When the relative motions and/or displacements between the atoms are in the same direction (upon the same line) as the wave propagation, the wave is called a compression, or longitudinal, wave. The compression wave is the fastest of all the elastic propagations that can be transmitted in a material. All forms of materials can support this kind, or mode, of wave, and it is the kind of wave that is normally generated by transducers. Figure 6.2(1) illustrates a compression wave.
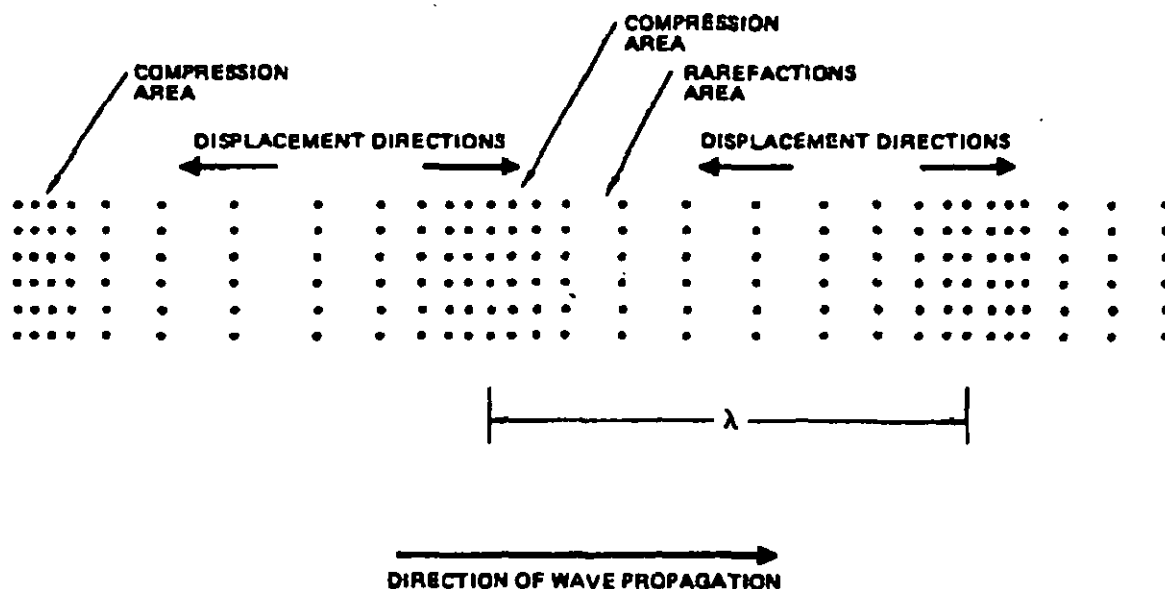
Figure 6.2(1). Compression or longitudinal wave motions.

The velocity of a longitudinal wave, V_L is:

$$V_L = \sqrt{\frac{Y(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}} = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \tag{9}$$

where

   Y = Young's modulus, force per unit area;

   ρ = density, mass per unit volume;

   σ = Poisson's ratio, dimensionless;

   μ = shear modulus, force per unit area;

   K = Bulk modulus, force per unit area.

This velocity equation assumes that the material is uniform and isotropic and that dimensions are large enough that surface effects are small. The longitudinal wave velocities for different materials are shown in Table 6.2(1).

Table 6.2(1). Acoustic properties of materials.

MATERIAL	DENSITY ρ=GM/CM³	LONGITUDINAL WAVES		SHEAR (TRANSVERSE) WAVES		SURFACE (RAYLEIGH) WAVES	
		VELOCITY V_L = CM/μSEC	IMPEDANCE Z_L = GMX 10^3/ CM² - SEC	VELOCITY V_T = CM/μSEC	IMPEDANCE Z_T = GMX 10^3/ CM² - SEC	VELOCITY V_R = CM/μSEC	IMPEDANCE Z_R = GMX 10^3/ CM² -SEC
AIR	0.001	0.033	0.33	–	–	–	–
ALUMINUM 250	2.71	0.635	1,720	0.310	840	0.290	788
ALUMINUM 17ST	2.80	0.625	1,750	0.310	868	0.279	780
BARIUM TITANATE	0.58	0.550	310	–	–	–	–
BERYLLIUM	1.82	1.280	2,330	0.871	1,600	0.787	1,420
BRASS (NAVAL)	8.1	0.443	3,610	0.212	1,720	0.195	1,580
BRONZE (P-5%)	8.86	0.353	3,120	0.223	1,980	0.201	1,780
CAST IRON	7.7	0.450	2,960	0.240	1,850	–	–
COPPER	8.9	0.466	4,180	0.226	2,010	0.193	1,720
CORK	0.24	0.051	12	–	–	–	–
GLASS, PLATE	2.51	0.577	1,450	0.343	865	0.314	785
GLASS, PYREX	2.23	0.557	1,240	0.344	765	0.313	698
GLYCERINE	1.261	0.192	242	–	–	–	–
GOLD	19.3	0.324	6,260	0.120	2,320	–	–
ICE	1.00	0.398	400	0.199	199	–	–
LEAD, PURE	11.4	0.216	2,460	0.070	798	0.063	717
MAGNESIUM, AM 35	1.74	0.579	1,010	0.310	539	0.287	499
MOLYBDENUM	10.09	0.629	6,350	0.335	3,650	0.311	339
NICKEL	8.8	0.563	4,950	0.296	2,610	0.264	2,320
OIL, TRANSFORMER	0.92	0.138	127	–	–	–	–
PLASTIC (ACRYLIC RESIN-PLEXIGLASS)	1.18	0.267	320	0.112	132	–	–
POLYETHYLENE	–	0.153	–	–	–	–	–
QUARTZ, FUSED	2.20	0.593	1,300	0.375	825	0.339	745
SILVER	10.5	0.360	3,800	0.159	1,670	–	–
STEEL	7.8	0.585	4,560	0.323	2,530	0.279	2,180
STAINLESS 302	8.03	0.566	4,550	0.312	2,500	0.312	2,500
STAINLESS 410	7.67	0.739	5,670	0.299	2,290	0.218	2,290
TIN	7.3	0.332	2,420	0.167	1,235	–	–
TITANIUM (TI 150A)	4.54	0.610	2,770	0.312	1,420	0.279	1,420
TUNGSTEN	19.25	0.518	9,980	0.287	5,520	0.265	5,100
WATER	1.00	0.149	149	–	–	–	–
ZINC	7.1	0.417	2,960	0.241	1,710	–	–

MIL-HDBK-728/6

b. <u>Shear, or Transverse, Waves</u>. When the relative motions and/or displacements between the atoms are in directions perpendicular to the wave propagation, the wave is called a shear, or transverse, wave. Only solids can normally support this kind, or mode, of wave. For any one material, shear waves travel at a slower velocity (approximately half) than the longitudinal waves, with, for equal frequencies, shorter wavelengths. The nature of this motion is illustrated in Figure 6.2(2).
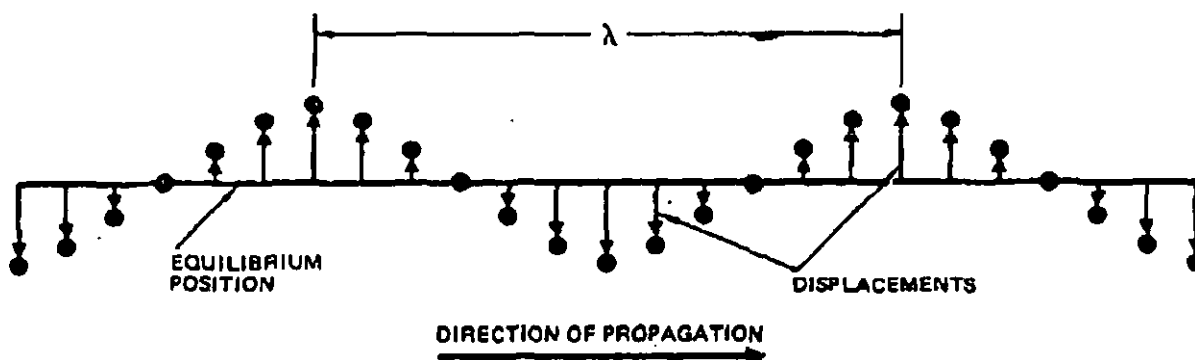

Figure 6.2(2). <u>Shear or transverse wave motions</u>.

The velocity of a shear wave, V_S, is:

$$V_S = \sqrt{\frac{\mu}{\rho}} = \sqrt{\frac{Y}{\rho} \frac{1}{2(1+\sigma)}} \qquad (10)$$

(See Equation 9 for definitions of variables.) Again, this equation assumes that the material is uniform and isotropic and has large enough dimensions that surface effects are small. See Table 6.2(1) for the shear wave velocities of various materials.

c. <u>Surface or Rayleigh Waves</u>. Surface or Rayleigh waves are a combination of shear and compression waves where the atom motion is elliptical. The larger amplitudes or the ellipse is perpendicular to the surface of the part. The wave motion is confined to the surface (or free boundary) of a solid of extensive thickness. For any one material, surface waves propagate with a velocity slightly less than for true shear waves (approximately $0.9V_S$). Their energy falls off sharply with distance into the material so that the majority of the energy is confined to within one wavelength of the surface. When a material is in air, these waves usually travel with less attenuation than longitudinal or shear waves in the same material, but if the material is in a liquid, or other non-negligible medium, the surface waves will quickly disappear. These waves will reflect at sharp edges, and so are effective for locating surface cracks, but they will propagate around smooth rounded edges and can be used to inspect parts that have complex contours if the contour radii are large compared to the wavelengths. Table 6.2(1) lists the surface wave velocities for different materials.

d. **Plate, or Lamb, Waves.** When a material is very thin, only a few
wavelengths in thickness, an infinite number of various waves can be
established that are a combination of both surface and bulk motions. These
complex interactions are called plate, or Lamb, waves. Lamb waves can consist
of one set of waves that is symmetrical about the center line of the plate or
another set that is asymmetrical. Each of these sets has an infinite number
of different orders or modes, each with different wavelengths and velocities.
The frequency of the wave and the plate thickness affect their velocities
along with the other normal material variables. In general, the wave
velocities can range from zero to almost the longitudinal propagation rate,
but any one mode will normally approach the transverse velocity (or more
correctly, the surface wave velocity) as the frequency or the relative
thickness of the plate increases. (In the mathematical descriptions of these
waves in certain other texts, the terms "phase" velocities and "group"
velocities are sometimes used. The "group" velocities are the velocities at
which the energy is actually transferred and should normally be used as the
velocity of the waves.)

6.2.2   GENERATION OF WAVES

Today, almost all high frequency ultrasonic beams are generated by transducers
that transform electrical energy into mechanical wave energy by the piezo-
electric effect. Materials such as quartz, lithium sulfate, and polarized
ceramics will slightly change their dimensions when an electric charge is
applied across opposing faces of the material. The reverse also occurs. When
these materials are forced to change their dimensions, the change in dimensions
produces a charge of electricity. This effect allows the same transducer to
be used as a transmitter to convert electrical signals into a mechanical wave,
and then to act as a receiver to detect the return mechanical wave signals and
reconvert them back into electrical signals.

Different types of piezoelectric materials have different properties, and the
materials vary in their abilities to act as transmitters or as receivers. The
materials differ in their chemical, electrical and thermal stabilities, and in
their wear-resistance and expected life-time in use. Table 6.2(2) lists some
piezoelectric materials and their main characteristics.

Table 6.2(2). *Piezoelectric material characteristics.*

MATERIALS	CHARACTERISTICS
QUARTZ.	QUARTZ HAS EXCELLENT CHEMICAL, ELECTRICAL, AND THERMAL STABILITY. IT IS INSOLUBLE IN MOST LIQUIDS AND IS VERY HARD AND WEAR-RESISTANT. QUARTZ ALSO HAS GOOD UNIFORMITY AND RESISTS AGING. IT IS THE LEAST EFFICIENT GENERATOR OF ACOUSTIC ENERGY OF THE COMMONLY USED MATERIALS AND REQUIRES HIGH VOLTAGE TO DRIVE IT AT LOW FREQUENCIES.
CERAMIC. (E.G. BARIUM TITANATE, LEAD METANIOBATE, OR LEAD ZIRCONATE TITANATE.	POLARIZED CERAMIC TRANSDUCERS ARE THE MOST EFFICIENT GENER- ATORS OF ULTRASONIC ENERGY: THEY OPERATE WELL ON LOW VOLTAGE, ARE USABLE UP TO ABOUT 300C. THEY ARE LIMITED BY RELATIVELY LOW MECHANICAL STRENGTH, AND HAVE A TENDENCY TO AGE.
LITHIUM SULFATE.	LITHIUM SULFATE TRANSDUCERS ARE THE MOST EFFICIENT RECEIVERS OF ULTRASONIC ENERGY AND ARE INTERMEDIATE AS A GENERATOR OF ULTRASONIC ENERGY. THEY DO NOT AGE. LITHIUM SULFATE IS VERY FRAGILE, SOLUBLE IN WATER, AND LIMITED TO USE AT TEMPERATURE BELOW 74C.

Transducers come in different sizes and configurations. Normally, a small transducer produces higher frequencies and sharper geometric resolutions, but they normally produce very little energy. A large transducer produces more energy with smaller ultrasonic beam angles (less beam spread), and therefore provides deeper penetrations. Transducers can be designed to produce beams at various angles that can be used to obtain shear waves. Transducers can be designed to produce beams wider than they are deep (for a "paint brush" like inspection), or they can be made to focus the ultrasonic beam towards a focal point or line.

One of the most important variables of a transducer is its frequency spectrum. The transducer, depending upon its use, may need to have a very broad band (highly damped for critical depth resolutions), or a very narrow band (a ringing transducer that can produce a large amount of energy). The frequency must often be matched with the material, the expected attenuation losses, the expected type and size of flaws, and the geometry of the part. Therefore, the choice of a transducer is often critical in the success of any particular test. Vendor data should be obtained on the transducer to determine these variables and a selection of transducers should always be available to optimize each test to the specific conditions or requirements of the test.

6.2.3   BEAM PROPAGATION LIMITS

In ultrasonics, the inspection is almost always done with an ultrasonic beam. Beam physics are important in the generation and propagation of a beam. Since an ultrasonic beam is not anything concrete in itself, but is really a group action of a large number of atoms (or molecules), there are real limits in what a "beam" of ultrasonic energy can do.

First of all, a beam of ultrasonic energy does not and cannot have sharp boundaries. A distribution of energy normally exists across the width of a beam with the maximum energy near the center of the beam and with the energy decreasing as the "edges" are approached. Distribution of the ultrasonic beam energy can only be in ways that can be maintained by group actions of the atoms that make up the medium. When ultrasonic energy is produced by a transducer, the face of the transducer, in its motion, is not producing the exact same energy distribution that is necessary to sustain a steady beam.*
It takes a finite amount of time, or distance, before the energy in a beam can become "adjusted" to an in-phase steady condition. The area wherein this out-of-phase is occurring is known as the near-field zone or area. Within the near-field zone, the ultrasonic beam is very unstable and inconsistant from point to point and normally inspections in this zone should be discouraged. The dimension of the near field can be approximated by Equation 11 using the diameter, D, of the face of the transducer and the ultrasonic wavelength, :

$$\text{Near-field dimension} \approx \frac{D^2}{4\lambda} \tag{11}$$

*"That is, the face of the transducer does not vibrate back and forth like the head of a piston. Rather, the face of a transducer vibrates with stationary node points; adjacent segments vibrate 180 degrees out of phase to one another. This complex movement causes reinforcement and cancellations in the near field".

As can be seen from this equation, the near-field dimension can be reduced by increasing the wavelength (or lowering the frequency), or by decreasing the diameter of the transducer.

Even after beam stability is achieved, the natural result of the group actions of atoms produces a slow divergence of the beam. Equation 12 gives an approximate estimation of the beam spread:

$$\theta = \sin^{-1}\left(\frac{1.2\lambda}{D}\right) \tag{12}$$

This angle, , represents half the apex angle of a cone within which the total energy of the primary beam is travelling. Figures 6.2(3) and (4) illustrate these relationships. The angle at which the energy of the beam has decreased to one-half of the maximum energy that exists at the center of the beam (the half-power angle) is:

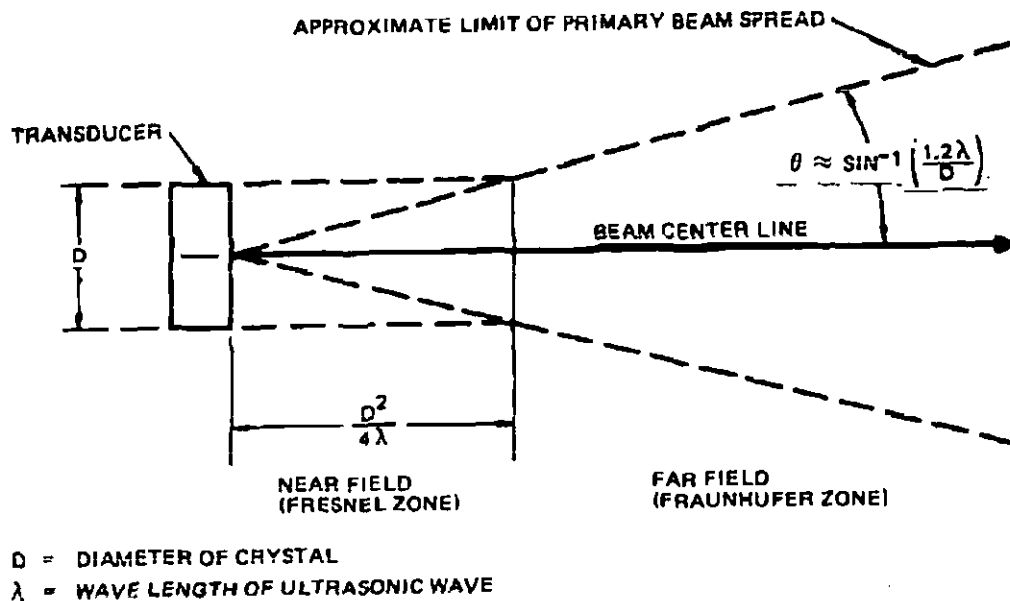$$\theta_{\frac{1}{2}} = \sin^{-1}\left(\frac{0.72\lambda}{D}\right) \tag{13}$$

If the transducer's face is small compared to the ultrasonic wavelength, side lobes will be produced as beam stability is obtained. (These side lobes can be greatly affected by the mounting of the transducer crystal and the freedom of motion that exists at the edges of the crystal.)

Because waves are group actions of atoms, an ultrasonic beam cannot be focused to a sharp point. When a point focus of an ultrasonic beam is attempted, the beam approaches a point, but near the focus point it forms a "chimney" (a fixed-width path) from which it again spreads out beyond the focal point. This chimney effect often provides a reasonable path length over which inspection resolutions are fairly constant, but normally at no point can the expected geometric resolutions be much better than one wavelength.

In ultrasonics, a pulse of energy rather than a continuous wave is often desired. Again, because an ultrasonic wave pulse is dependent upon the group actions of atoms, there is a finite limit to the length of the pulse (the extent of space it must occupy in the direction of its propagation). This limitation again approaches approximately one wavelength. In addition to this geometric limit, a wave pulse becomes limited in its frequency representation as its pulse length decreases. This kind of relationship exists for all forms of waves and is not due to the limitations caused by group actions of atoms. In general, if we let X equal the "length" of a wave pulse, and $\Delta\lambda$ the range of wavelengths that have appreciable amplitude representations within this pulse, then:

$$(\Delta X)(\Delta\lambda) \geq \lambda_o^2 \tag{14}$$

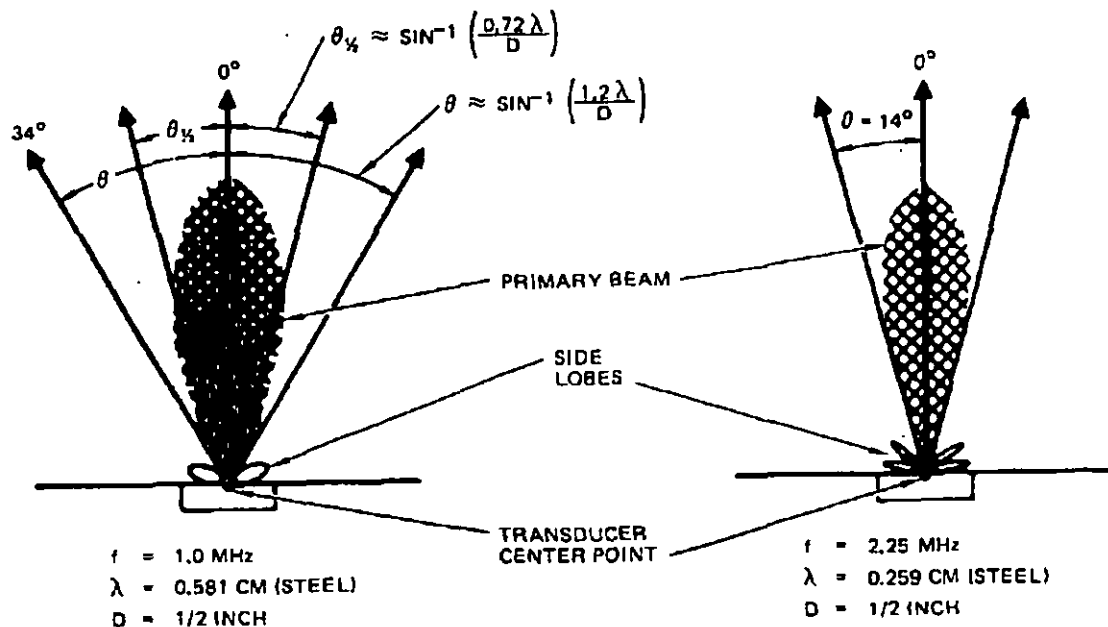where λ_o represents the center, maximum, or primary wavelength.

APPROXIMATE LIMIT OF PRIMARY BEAM SPREAD

TRANSDUCER

$\theta \approx \sin^{-1}\left(\frac{1.2\lambda}{D}\right)$

BEAM CENTER LINE

D

$\frac{D^2}{4\lambda}$

NEAR FIELD
(FRESNEL ZONE)

FAR FIELD
(FRAUNHOFER ZONE)

D = DIAMETER OF CRYSTAL
λ = WAVE LENGTH OF ULTRASONIC WAVE

BEAM SPREAD ANGLES, θ, IN STEEL FOR DIFFERENT FREQUENCIES
AND DIFFERENT SIZE TRANSDUCERS

FREQUENCY MHz	λ CM (STEEL)	TRANSDUCER DIAMETER (D) INCHES			
		3/8	1/2	3/4	1.0
1.0	0.581	48°10'	34°	21°52'	16°13'
2.25	0.259	19°23'	14°25'	9°33'	7°9'
5.0	0.116	8°34'	6°25'	4°16'	3°12'

Figure 6.2(3). Near-field dimensions and beam-spread angles.

When ΔX becomes small, $\Delta \lambda$ becomes large, and the wave pulse then becomes subjected to dispersions and differential attenuations because of the wide range of frequencies that are effectively present.

The importance of the length of the wave pulse cannot be overlooked. When inspecting a material in which depth information is important, the length of the wave pulse produces a "dead zone" which limits the depth resolutions that can be obtained. This dead zone (often referred to as "ringing") limits how close the transducer can inspect from its own face, and limits the inspection distance from all other interfaces that produce measurable return signals.

$$\theta_{1/2} \approx \sin^{-1}\left(\frac{0.72\lambda}{D}\right)$$

$$\theta \approx \sin^{-1}\left(\frac{1.2\lambda}{D}\right)$$

PRIMARY BEAM

SIDE LOBES

TRANSDUCER CENTER POINT

f = 1.0 MHz
λ = 0.581 CM (STEEL)
D = 1/2 INCH

f = 2.25 MHz
λ = 0.259 CM (STEEL)
D = 1/2 INCH

NOTE

IN THIS FIGURE, THE "DISTANCE" FROM A TRANSDUCER CENTER POINT TO A POINT ON A PROFILE REPRESENTS INTENSITY AND NOT DISTANCES TO POINTS IN THE ULTRASONIC FIELD. THIS TYPE OF INTENSITY PROFILE EXISTS IN THE FAR FIELD ONLY, AND REPRESENTS THE PROFILE MEASURED AT A FIXED DISTANCE IN THIS FIELD. THE PROFILE GIVES ONLY RELATIVE INTENSITIES, THE ACTUAL INTENSITIES WOULD VARY WITH BOTH THE ANGLE AND THE DISTANCE AT WHICH IT IS MEASURED. A DRAWING OF CONTOUR INTENSITIES, AS THEY WOULD EXIST ON A DISTANCE PLOT, WOULD BE SIMILAR TO THIS FIGURE IN PLACES, BUT THEY DEFINITELY ARE NOT THE SAME.

Figure 6.2(4). Far-field intensity profile.

The dead zone is not the same as the near-field zone, although both affect the inspectability close to the transducer. On an A-scan (see paragraph 6.2.5), the dead zone would be indicated by the width of the pulses shown on the scan.

6.2.4   INTERACTIONS OF ULTRASONIC WAVES WITH MATERIAL VARIABLES

Ultrasonic wave interactions with materials include transmissions, reflections, refractions, diffractions, mode conversions, scattering and absorption. There also exists standing waves and constructive and destructive interferences, usually associated with reflection and diffractions. Reflections, refractions, and mode conversions can occur at an interface between two different materials. These interactions depend upon the difference in the acoustic impedances of the two materials (impedance mismatch) and on the angle of incidence of the ultrasonic beam.

Figure 6.2(5) shows a transducer sending a longitudinal wave into water. The water transmits the beam to the test piece, a block of steel. When the longitudinal (L) wave is incident to the surface of the test specimen in the normal (perpendicular) direction, 0° incidence, the beam is transmitted into the second medium as a longitudinal beam. No refraction and no mode conversions take place. Not all of the energy, however, enters into the steel. Some of the energy (most of it, in this particular case) is reflected.

6.2-11
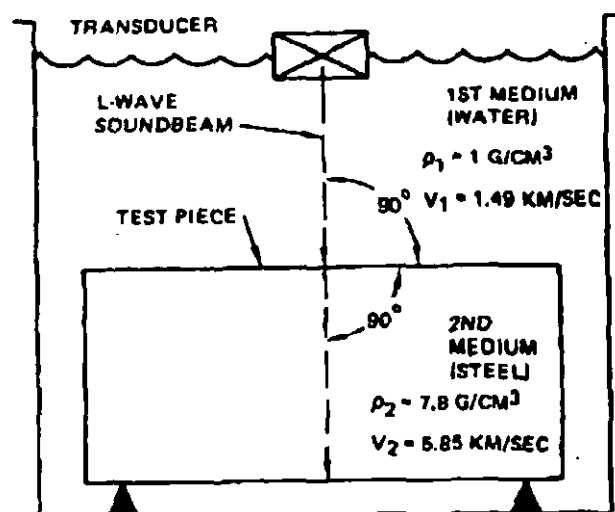
Figure 6.2(5). Normal incident beam.

The maximum pressure amplitude of the reflected wave, P_r, for 0° incidences, is:

$$P_r = P_o \left(\frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1} \right)$$ (15)

where

P_o = Maximum incident pressure amplitude

ρ_1 = density of the first medium (incident side)

ρ_2 = density of the second medium

V_1 = Wave velocity of the first medium

V_2 = Wave velocity of the second medium

For steel, as shown in Figure 6.2(5), the amplitude of the reflected wave would be approximately $0.94\ P_o$. Note that the reflected wave is large when there is a large difference in the acoustic impedance and that the reflected wave would disappear (have zero pressure amplitude) if the two materials had identical acoustic impedances. (If the two materials were identical, it would be the same as if there were no interface, and therefore no reflections could be expected.) Also note that the sign of the pressure of the reflected wave is opposite to the incident pressure sign when the acoustic impedance of the first medium is greater than that of the second. The change in sign means that a positive pressure pulse would be reflected as a rarefaction (a negative

pressure pulse), or a negative pressure pulse would reflect as a positive pressure pulse. The energy or intensity that is reflected, I_r, is:

$$I_r = I_o \left(\frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1} \right)^2 \tag{16}$$

where I_o represents the intensity of the incident beam.

The pressure and intensity of the transmitted wave, P_t and I_t, are:

$$P_t = P_o \left(\frac{2 \rho_2 V_2}{\rho_2 V_2 + \rho_1 V_1} \right) \tag{17}$$

$$I_t = I_o \left(\frac{4 \rho_2 V_2 \rho_1 V_1}{(\rho_2 V_2 + \rho_1 V_1)^2} \right) \tag{18}$$

These equations show that as long as a second medium exists, it will always transmit a pressure and it is always in the same phase or sign as the incident wave. These equations are the natural results of conservation of energy (using the pressure relationships of Equation 8 and setting $I_o = I_r + I_t$), the pressure being continuous across an interface, and that small pressures from two or more waves add linearly (setting $P_o + P_r = P_t$). These relationships, when solved simultaneously, produce Equations 15 through 18.

Equations 15 through 18 all assume semi-infinite mediums on each side of the boundary. When actual geometrics are small, with edges or back surfaces near the point of incidence, these equations often break down. In some literature, a "specific acoustic impedence" term is used to account for these differences. One of the important interactions affecting these relationships is standing waves or interferences that can be developed when thicknesses approach the dimensions of a small number of wavelengths and/or is less than one-half of the pulse length. Thicknesses that are exact multiples of half-wavelengths will experience an increase in transmission energies and a minimum in reflection energies. Thicknesses that are odd quarter-wavelengths will experience a decrease in transmission energies and an increase in the reflected energies. The reflected energy can often be made to approach zero, but the transmitted energy will always be finite. Attenuation losses, if present, will reduce these interference effects.

In ultrasonic testing, you cannot inspect a part unless beam energy is able to penetrate the part and then return to a receiver. It cannot do this without passing through several interfaces. Each time an interface is crossed, potentially a large percentage of the energy can be lost.

Using Equation 18 for water and steel, only 12% of the energy will enter the steel. If all of this energy inside the material could be reflected back (which of course is not likely), this energy must still return back through the steel-water interface, and the same loss factor will occur again. Only 1.4% (12% of 12%) of the energy can return to the transducer, even if there were no other losses. Table 6.2(3) lists some of the energy reflections expected at the interfaces of various materials.

Table 6.2(3). Percentage of energy reflected.

ONE MEDIUM	SECOND MEDIUM												
	ALUMINUM	STEEL	NICKEL	COPPER	BRASS	LEAD	MERCURY	GLASS	QUARTZ	POLY-STYRENE	BAKELITE	WATER	OIL
ALUMINUM	0	21	24	18	14	3	1	2	0.3	60	42	72	74
STEEL		0	0.2	0.3	1	9	16	31	27	77	76	68	89
NICKEL			0	0.8	2	12	19	34	29	79	75	89	90
COPPER				0	0.2	7	13	19	22	75	71	87	88
BRASS					0	5	10	23	16	73	68	86	87
LEAD						0	1	9	8	62	55	79	80
MERCURY							0	4	1	6	6	75	76
GLASS								0	0.8	40	32	65	67
QUARTZ		SAME VALUES HERE AS FOR OPPOSITE POSITIONS ACROSS THE DIAGONAL							0	46	17	68	71
POLYSTYRENE										0	1	12	17
BAKELITE											0	18	23
WATER												0	0.6
OIL (TRANSFORMER)													0

NOTE
FOR ENERGY, THE ORDER OF THE MEDIUMS ARE NOT IMPORTANT. THE SAME ENERGY IS REFLECTED WITH PROPAGATION GOING IN WATER TOWARDS STEEL OR IN STEEL TOWARDS WATER.

The final energy received can often be a thousandth of the initial energy. Knowledge of these energy losses, and how to control them, are therefore important. In order to get energy into a part, a couplant must normally be used. This is a grease or other liquid or paste-like material.

When use of a couplant is required between a transducer and a specimen,
minimum loss of energy occurs when an impedance match is achieved.
Theoretically, a maximum impedance match is obtained when:

$$Z_c = \sqrt{Z_1 Z_2} \qquad\qquad (19)$$

where

Z_c = impedance of the couplant

Z_1 = impedance of first medium (transducer)

Z_2 = impedance of second medium (specimen)

As the incident angle is changed from the initial zero degrees incident to a
value like 5 degrees, as shown in Figure 6.2(6), refraction and mode
conversion occur. The original longitudinal beam is transmitted, in the
second medium, as varying percentages of both longitudinal (L) and shear (S)
wave beams. As shown, the refracted angle for the L-wave beam is four times
the incident angle, and the S-wave beam angle is a little more than twice the
incident angle. If the incident angle is increased further, the refraction
angles of the L-wave and the S-wave increase. The energy in each beam also
varies as the angle is changed.
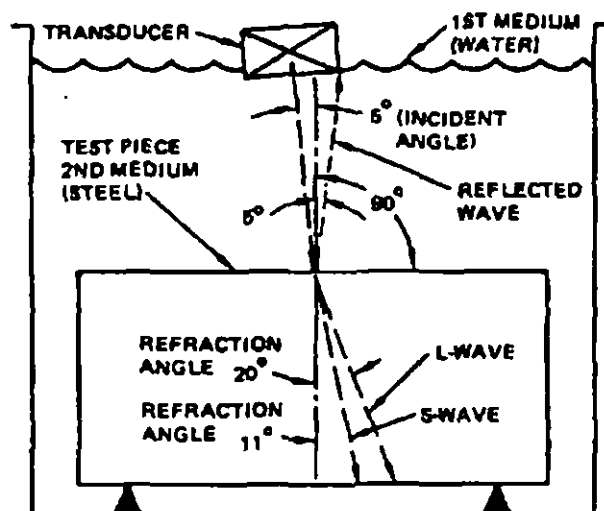
Figure 6.2(6). Five-degree incident beam.

The laws of reflection angles and refraction angles are all based on Snell's
Law, that the ratios of the velocities to the sines of the angles are equal.

In equation form:

$$\frac{\sin\theta_i}{V_i} = \frac{\sin\theta_r}{V_r} = \frac{\sin\theta_t}{V_t} \tag{20}$$

where

θ_i = incident angle

V_i = velocity of incident wave

θ_r = reflected beam angle

V_r = velocity of reflected wave

θ_t = transmitted beam angle

V_t = velocity of transmitted wave

Since the reflected beam is always in the same medium as the incident beam, then their velocities are equal (unless a mode conversion has occurred). If their velocities are equal, then the angle of reflection will be equal to the angle of incident. The transmitted wave, however, is in a different medium, and thus the velocities will normally be different (whether mode conversions occur or not) and thus a change in angles will be expected. If mode conversions occur and more than one type of wave exists, they will each have a different velocity, and thus a different angle of refraction. Since the shear wave velocity is less than the longitudinal wave velocity, it will always have the smallest angle of refraction. As the incident angle is further increased, both refracted angles will increase. The first beam to reach a refraction angle of 90 degrees will be the L-wave.

In Figure 6.2(7) the transducer has been rotated (in this case, 15 degrees) until the refracted angle of the L-wave has increased to 90 degrees. At this point, the L-wave no longer exists in the material. The incident angle at which this occurs is called the first critical angle, the angle where the L-wave first "disappears" and only S-waves remain in the material. (The actual amplitude of the S-wave, at this point, may be very small, but it is there.) Further rotation of the transducer increases the angle of the refracted shear wave beam. When the S-wave beam reaches 90 degrees, the incident angle is positioned at the second critical angle. In the entire region between the first and second critical angle, only S-wave beams are produced within the material.

Tables 6.2(4) and (5) provide critical angles for different material interfaces.

Figure 6.2(8) shows the transducer rotated enough (27 degrees in this case), so that the S-wave refraction angle has reached 90 degrees. At this point, no ultrasonic beams of any mode now appear in the material. At the surface, the beam has undergone mode conversion to a surface wave. Because the surface
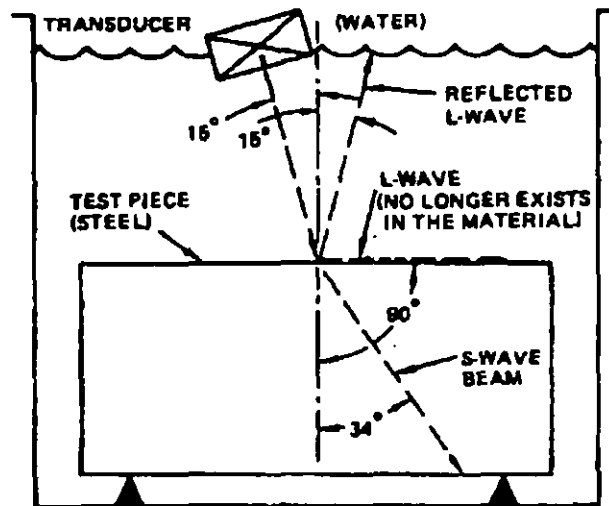
Figure 6.2(7). First critical angle.

Table 6.2(4). Critical angles, immersion testing.

FIRST MEDIUM IS H_2O (V = 0.149 CM/μSEC)

TEST MATERIAL	1ST CRITICAL ANGLE	2ND CRITICAL ANGLE	VELOCITY (CM/μSEC).	
			LONGITIDUNAL	SHEAR
BERYLLIUM	7°	10°	1.280	0.871
ALUMINUM, 17ST	14°	29°	0.635	0.310
STEEL	15°	27°	0.585	0.323
STAINLESS 302	15°	29°	0.566	0.312
TUNGSTEN	17°	31°	0.518	0.287
URANIUM	26°	61°	0.338	0.193

is in water, the surface waves are quickly damped out. In contact testing, where the test specimen is in air and surface waves are produced on the test piece when the second critical angle is reached, they can travel much longer distances before they are damped out.

In ultrasonic testing, the incident beam, because of beam spread, is a "collection" of angles or directions (see section 6.2.2 and Figures 6.2(3) and (4)). Therefore, when a beam is "at" a critical angle, actually half of the energy of the beam is at angles greater than this critical angle and the other

Table 6.2(5). Critical angles, contact testing.

FIRST MEDIUM IS PLASTIC (V = 0.267 CM/μSEC)

TEST MATERIAL	1ST CRITICAL ANGLE	2ND CRITICAL ANGLE	VELOCITY (CM/μSEC).	
			LONGITUDINAL	SHEAR
BERYLLIUM	12°	18°	1.280	0.871
ALUMINUM, 17ST	25°	59°	0.626	0.310
STEEL	27°	56°	0.585	0.323
STAINLESS, 302	28°	59°	0.566	0.312
TUNGSTEN	31°	68°	0.518	0.287
URANIUM	52°	--	0.338	.0.193
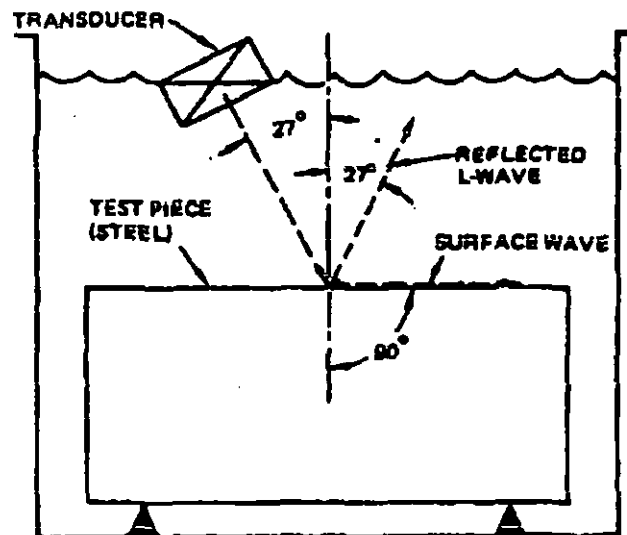
Figure 6.2(8). Second critical angle.

half at angles less than this critical angle. When a beam is "at" any particular angle of incidence, refractions are actually occurring over potentially a large range of angles. Therefore, it is possible to have in a part a great number of waves, wave directions and modes, many more than what might be theoretically expected. Within the part, if there are any complications at all to the part, or sometimes even when it is a simple part, the number of internal reflections, mode conversions, and refractions quickly multiply at every interface until there are more beams than can readily be tracked. Part of the "art" or "science" of ultrasonic testing is to always watch for unexpected beams and their reflections and to always double check that only the "proper" beams or reflections are being recorded.

Attenuation of ultrasonic energies arise from several factors. First, normal beam spread results in a loss due to geometric effects and involves the same $1/r^2$ factor used in X-rays or any other type of radiating energy ("r" is the distance from a point source.) The origin for r should be the face of a small, straight beam transducer when test points are beyond the near field or the focal point for a focus transducer. Additional attenuations can result from diffractions, reflections and refractions. All of these can be called scatter when they occur randomly or from multiple small distributive variables contained within the material.

Diffraction is a change in the direction of a wave in one material medium as the wave passes close to the edge of another medium. Diffraction is often involved around the edges of parts or the edges of internal flaws.

Energy losses can be due to absorption processes that result in heating effects. These losses within the material can be due to friction or physical imperfections in the arrangements of the atoms in crystals or grains, or other non-linearities in the kinetic energy-potential energy exchanges that occur when waves propagate. These losses are a function of frequency.

When energy losses occur uniformly throughout a material, the overall attenuation for a parallel beam follows the power law:

$$I(x) = I_o e^{-Kx} \tag{21}$$

where

$I(x)$ = the intensity at position x

I_o = intensity at the position x = 0

K = attenuation constant

x = penetration distance .

The attenuation constant is greatly affected by frequency or wavelength compared to the size of the variables causing the scatter. Normally, the lower the frequency (the longer the wavelength), the lower the attenuation constant "K", the greater the penetration. (Attenuation constants can be given for wave pressure losses and/or for a base 10 relationship. Care must be exercised here because they will differ by a factor of 0.5 and/or 0.868 from the above defined constant.)

When a wavelength is much larger than the size of the object causing the scattering, it "flows" around the object and essentially continues on its way with no major losses or changes. This is good if it is not the variable to be inspected. This relationship, however, does point out the importance of testing with high frequencies. The size of defects that can be seen will be greatly affected by the frequency being used. The higher the frequency, the smaller will be the size of flaws that can be resolved. If the wavelength is smaller than the object causing the scattering, it will interact with that

object and be reflected and transmitted by the principles previously presented. Therefore, most ultrasonic testing requires a balance between using the highest frequency possible to find the smallest possible flaws, yet keeping the frequency low enough that adequate penetrations can be obtained. Since higher frequencies create more noise, improved flaw detection signal-to-noise ratios are obtained from lower frequencies. Every inspection problem potentially has a unique choice where this relationship is maximized.

6.2.5 INFORMATION DISPLAYS

Most ultrasonic information is presented on an oscilloscope, where time is represented on the horizontal axis (or sweep direction) and the amplitude of the ultrasonic energy either being sent or received by the transducer is recorded in the vertical direction. The start of the time sweep on the horizontal is "triggered" by each transmitted pulse. The transmitted pulse is therefore the first signal or pip usually seen on the screen. The repetition rate of the transmitted pulses, and thus the signal on the screen, is fast enough that it appears continuous to the eye. Between each transmitted pulse, echoes are received back by the transducer. These echoes, depending on the distance from which they are returned, are each received at different times. In exactly the same order, each echo appears on the screen at different points along the sweep line. Each return pulse can normally be shown as "rf," where their full wave action, the plus and minus pressures in each cycle, are indicated; or the rf signal can be rectified to provide a dc pulse. The electrical amplification circuits normally have a saturation limit so that signals that would be amplified beyond a certain point on the screen all appear at the same maximum level.

The sweep circuit actually contains a delay circuit (sometimes called sweep delay) and a sweep rate control (sometimes called sweep length) which allows any portion of the total sweep to be amplified and displayed on the full screen. This display shown on the screen, where amplitude versus time is showing the echoes being received at different depths in the part, is called an A-scan. An A-scan is essentially examining the specimen along the beam line, penetrating through the specimen through only one point on the surface above which the transducer is located. To inspect an entire part by the A-scan method would require moving the transducer over every point of the surface, and observing the A-scan obtained at each point.

A B-scan is a display that shows a cross-section of a part. It is "obtained" from the A-scans produced at all the points along one line across the surface of the specimen, and thus provides in one picture a summation of what might otherwise be an unmanageable amount of information.

A B-scan display, therefore, shows the section view of a material that was "cut" (or penetrated) by an ultrasonic beam as the transducer made a one line pass across the material. On a cathode ray tube, the image is formed by a series of parallel lines, each line representing data from a single A-scan.

The distance between each line represents the distance the transducer was moved between each A-scan. Each line is formed by a spot moving across the screen whose brightness at each point is a function of the signal amplitude at that corresponding point on the A-scan.

To inspect an entire part by B-scans would require the forming of a B-scan for all the cross-section lines that exist across any one dimensional direction of the part. This, too, could still be a large number of scans and/or information to be analyzed.

A C-scan is a plan-view of the entire part. In one view, all the information, or a portion of the information, from all the A-scans can be combined and shown in this view. By use of an electronic gate, the information collected from the A-scans can be limited to a specific range of depths. If only a narrow portion of each A-scan is used, then a cross-section parallel to the inspection plane can essentially be formed. If the electronic gate is expanded to include the full depth of the inspected part, then any A-scan that showed an echo within the depth of the part would produce a mark on the C-scan. In this way, a C-scan can be a great summation of information. When a C-scan is used to collect information over the full depth of a part, a mark on the C-scan will appear no matter where the signal appears within the width of the gate. Therefore, depth information on a C-scan is always uncertain by the depth or width of the gate used. There are times, therefore, when both A-scans and C-scans are used together when more information is required than what is provided by the C-scan.

THIS PAGE INTENTIONALLY LEFT BLANK

MIL-HDBK-728/6

6.3 EQUIPMENT AND MATERIALS

Ultrasonic equipment range from small portable units to large permanent facilities - some are manually operated, some have been automated in several features to include automatic scanning of specimens and recording of the information. Basic A-scan, B-scan, or C-scan type of recording methods can be used. Special types of ultrasonic equipment can be obtained to measure thicknesses, speed of ultrasonic waves, or changes in impedances. The degree of automation, the means of data analyses, and types of data displays are constantly improving largely because of recent advances in microprocessors.

Along with the basic equipment, there are transducers, automatic scanning and manipulator systems, tanks, couplant materials, and calibration and standard blocks necessary to support ultrasonic testing activities.

In immersion testing, clean, deaerated tap water, with an added wetting agent, can be used for a couplant. A fungicide and corrosion inhibitor are typically included in the immersion bath for protection. The water temperature is sometimes maintained at a fixed value by automatic controls. Wetting agents are added to the water to ensure that the surface is thoroughly wet, thereby eliminating air bubbles.

In contact testing, the choice of couplant depends primarily on the test conditions; i.e., the condition of the test surface (rough or smooth), the temperature of the test surface, and the position of the test surface (horizontal, slanted, or vertical).

One part glycerine with two parts water, and a wetting agent, is often used on relatively smooth, horizontal surfaces. For slightly rough surfaces, light oils (such as SAE 20 motor oil), with a wetting agent added, are used. Rough surfaces, hot surfaces, and vertical surfaces require the use of a heavier oil, or grease, as a couplant. In all cases, the couplant selected must be capable of forming as thin a film as possible consistent with the geometric variables that are present.

It must be understood that, other than for special portable type equipment like thickness gages, most ultrasonic testing systems require extensive electronic and mechanical support. The electronic effort is at least as technical as that required to set up and use an oscilloscope, and the mechanical support often includes automatic moving machinery with position and velocity limit controls.

MIL-HDBK-728/6

THIS PAGE INTENTIONALLY LEFT BLANK

6.4 BASIC PROCEDURES AND TECHNIQUES

Ultrasonic testing, like other NDT testing, provides indications that are of no value unless interpretations can be made. Interpretations are often dependent upon calibrations or standardizations that must be performed, either before, during, or after each test. Some of the means of obtaining these calibrations or standardizations are presented in the "Standards" section, section 6.5.

Because ultrasonic testing can involve a large number of variables, and some of these variables are external variables such as temperature that have a direct affect on the velocity and the wavelengths of the waves being used, the importance of the calibration cannot be overemphasized. Once adjustments have been made that establish the proper responses of the equipment and adequate indications of known discontinuities of the range of sizes, depths, and orientations required for the test have been established, testing can be initiated. Once calibration and standardization have been accomplished, no further adjustments should be allowed unless restandardization of the equipment is accomplished.

Techniques of ultrasonic testing are accomplished with one of two basic methods: contact or immersion testing.

6.4.1   IMMERSION TESTING

In immersion testing, a waterproof transducer is used at some distance from the test specimen and the ultrasonic beam is transmitted into the material through a water path or column. The water distance appears on the display as a fairly wide space between the initial pulse and the front-surface reflection because of the reduced velocity of ultrasound in water. Because of this "distance" between the transducer and the specimen, near-field and dead zone type effects are usually minimal for immersion type testing. Also, with the transducer separated from the specimen and the coupling being automatic, the transducer is reasonably free to move, and therefore most automatic scanning methods are associated with the immersion testing method.

Any one of three techniques may be used in the immersion method: the immersion technique, where both the transducer and the test specimen are immersed in water; the bubbler or squirter technique, where the ultrasonic beam is transmitted through a column of flowing water; and the wheel transducer technique, where the transducer is mounted in the axle of a liquid-filled tire that rolls on the test surface. Figure 6.4(1) shows an example of the bubbler and the wheel-transducer techniques. An adaptation of the wheel transducer technique is a unit with the transducer mounted in the top of a water-filled tube. A flexible membrane on the lower end of the tube couples the unit to the test surface. In all three of these techniques, a further refinement is the use of focused transducers that concentrate the ultrasonic beam (much like light beams are concentrated when passed through a magnifying glass).
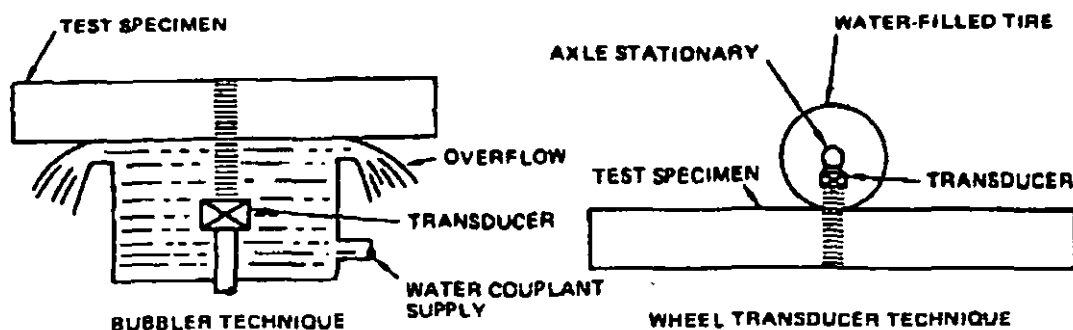
Figure 6.4(1). Bubbler and wheel transducer techniques.

In many automatic scanning operations, focused beams are used to detect near-surface discontinuities or to define minute discontinuities with the concentrated beam. Straight-beam transducer units can accomplish both straight- and angle-beam testing through manipulation and control of the beam direction.

The water-path distance is usually adjusted so that the time required to send the beam pulse through the water is greater than the time required for the pulse to travel through the test specimen. When done properly, the second front-surface reflection will not appear on the oscilloscope screen between the first front- and first back-surface reflections. In water, sound velocity is about one-quarter that of aluminum or steel; therefore, one inch of water path will appear on the oscilloscope screen as equal to four inches of metal path in steel. As a rule of thumb, position the transducer so that the water distance is equal to one-quarter the thickness of the part, plus one quarter inch. The correct water-path distance is particularly important when the test area shown on the oscilloscope screen is gated for automatic signalling and recording operations. The water-path distance is carefully set to clear the test area of unwanted signals that cause confusion and possible misinterpretation. Figure 6.4(2) shows the relationship between the actual water-path and the display.

The bubbler is usually used with an automated system for high-speed scanning of plate, sheet, strip, cylindrical forms, and other regularly shaped parts. The ultrasonic beam is projected into the material through a column of flowing water, and is directed in a normal direction (perpendicular) to the test surface to produce longitudinal waves or adjusted at an angle to the surface to produce shear waves.

Figure 6.4(3) illustrates a stationary and a moving-wheel transducer. The position and angle of the transducer mounting on the wheel axle may be constructed to project straight-beams, as shown in Figure 6.4(3), or to project angled beams as shown in Figure 6.4(4).
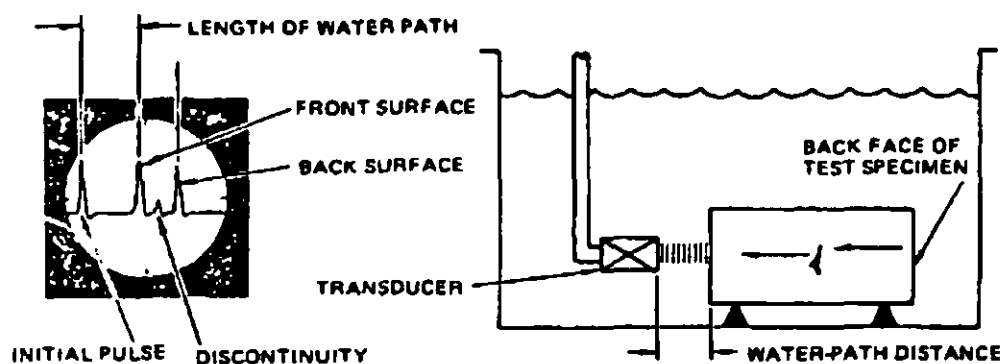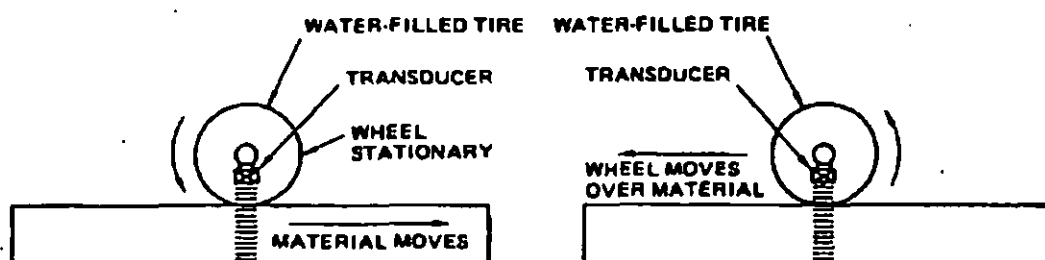
Figure 6.4(2). Water-path distance adjustment.

Figure 6.4(3). Stationary and moving wheel transducers.

6.4.2   CONTACT TESTING

In contact testing, the transducer is placed in direct contact with the test specimen with a thin liquid film used as a couplant. On some contact units, plastic wedges, wear plates, or flexible membranes are mounted over the face of the crystal. Transducer units are considered as being in contact whenever the beam is transmitted through a couplant other than water. The display from a contact unit usually shows the initial pulse and the front-surface reflection as superimposed or very close together. Both near-field and dead zone effects are present in contact type tests.

Contact testing is divided into three techniques, which are determined by the ultrasonic wave mode desired: the straight-beam technique for transmitting longitudinal waves in the test specimen, the angle-beam technique for generating shear waves, and the surface-wave technique for producing Rayleigh or Lamb waves.
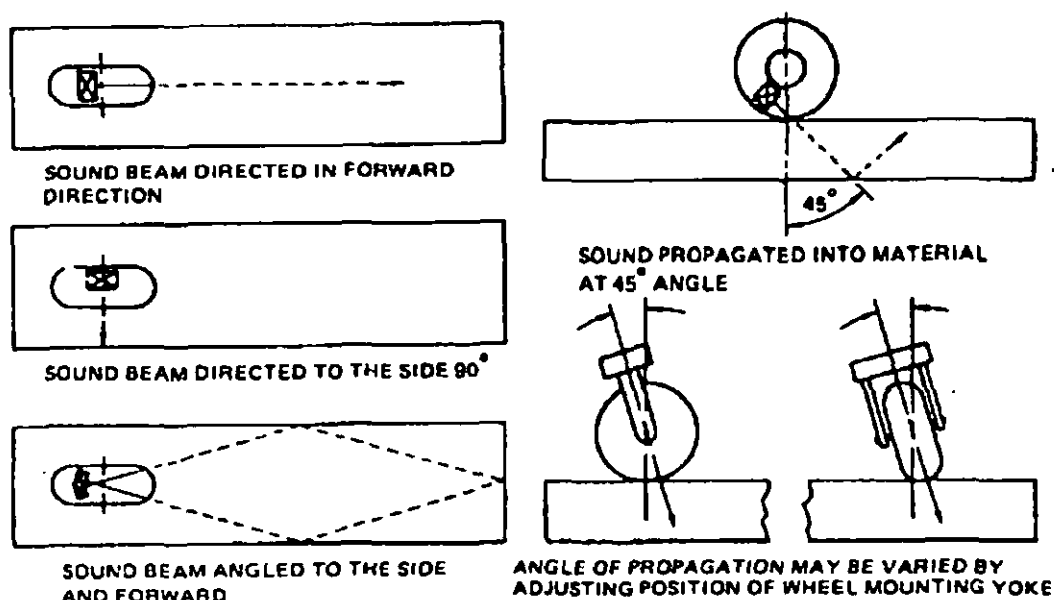
Figure 6.4(4). Wheel transducer angular capabilities.

The straight-beam technique is accomplished by projecting a beam
perpendicularly to the test surface of the test specimen to obtain pulse-echo
reflections (see Section 6.4.3) from the back surface or from discontinuities
which lie between the two surfaces. This technique is also used in the
through-transmission technique (see Section 6.4.3) using two transducers where
the internal discontinuities interrupt the beam causing a reduction in the
received signal.

The angle-beam technique is used to transmit sound waves into the test material
at a predetermined angle to the test surface. According to the angle selected,
the wave modes produced in the test material may be mixed longitudinal and
shear, shear only, or surface modes. Usually, the shear-waves are used in
angle-beam testing. Figure 6.4(5) shows an angle-beam unit scanning plate and
pipe material. To reduce the confusion from dead-zone and near-zone effects
encountered with straight-beam transducers, parts with a thickness less than
5/8 inch are tested with angle-beam units. In this technique, the beam enters
the test material at an angle and proceeds by successive zigzag deflections
from the specimen boundaries until it is interrupted by a discontinuity or
boundary where the beam reverses direction and is reflected back to the
transducer. Allowances are made when placing the angle-beam unit to account
for the lessened effective length of penetration because of the zigzag path
taken by the beam. Angle-beam techniques are used for testing welds, pipe or
tubing, sheet and plate material, and for specimens of irregular shape where
straight-beam units are unable to contact all of the surface. Angle-beam
transducers are identified by case markings that show beam direction by an
arrow and that indicate the angle of refraction in steel for shear waves.
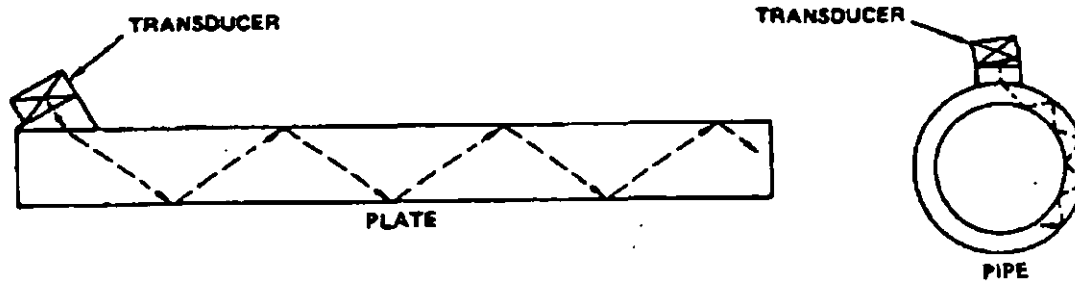
Figure 6.4(5).   Shear-wave technique.

The surface-wave technique requires special angle-beam transducers that project the beam into the test specimen at a grazing angle where almost all of the beam is reflected. For test specimens where near-surface discontinuities are encountered, surface-wave transducers are used to generate Rayleigh surface waves in the test material. The surface-wave technique is shown in Figure 6.4(6).
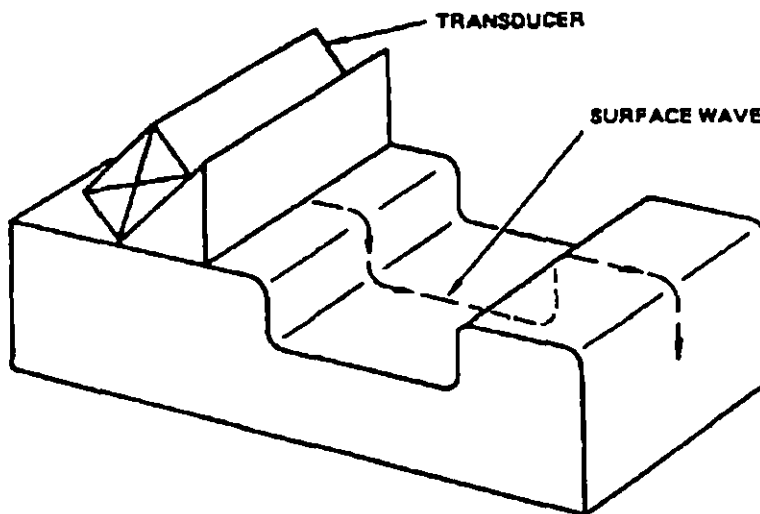

Figure 6.4(6).   Surface-wave technique.

6.4.3   PULSE-ECHO AND THROUGH TRANSMISSION

In both the immersion and in the contact test methods, there are pulse-echo techniques and through transmission techniques.

Pulse-echo techniques may use either single, or double, straight-beam transducers. Figure 6.4(7) shows a contact, single unit, straight-beam transducer in use. With the single unit the transducer acts as both
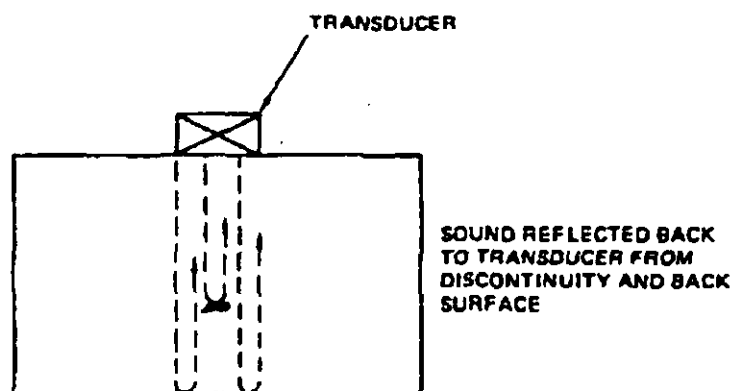
Figure 6.4(7).   Single-transducer pulse-echo technique.

transmitter and receiver, projecting a pulsed beam of longitudinal waves into
the specimen and receiving echoes reflected from the back surface and from any
discontinuity lying in the beam path with reflecting surfaces perpendicular to
the beam. The double transducer unit is useful when the test specimen flaws
or back surface are irregular or are not parallel with the front surface. One
transducer transmits and the other receives, as shown in Figure 6.4(8). In
this case, the receiver unit is receiving back-surface and discontinuity
echoes, even though both transducers may not be directly over these reflectors.
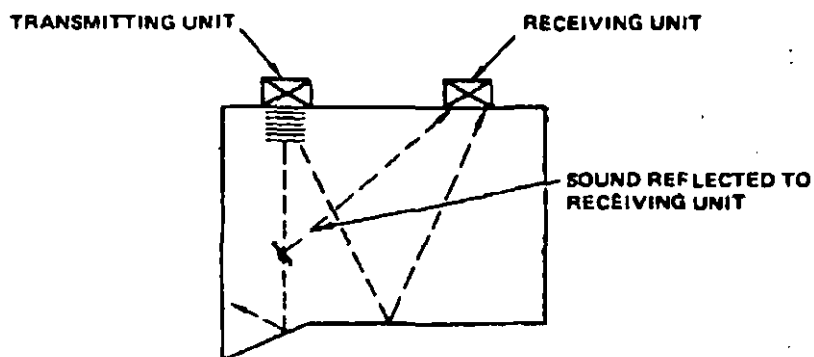
Figure 6.4(8).   Double-transducer pulse-echo technique.

Two transducers are usually used in the through-transmission technique - one
on each side of the test specimen, as shown in Figure 6.4(9). One unit acts
as a transmitter and the other as a receiver. The transmitter unit projects a
beam into the material, the beam travels through the material to the opposite
surface, and the energy is picked up at the opposite surface by the receiving
unit. Any discontinuities in the path of the beam cause a reduction in the
amount of energy reaching the receiving unit. For best results in this

6.4-6

TRANSMITTING UNIT   RECEIVING UNIT

DISCONTINUITY REDUCES AMOUNT
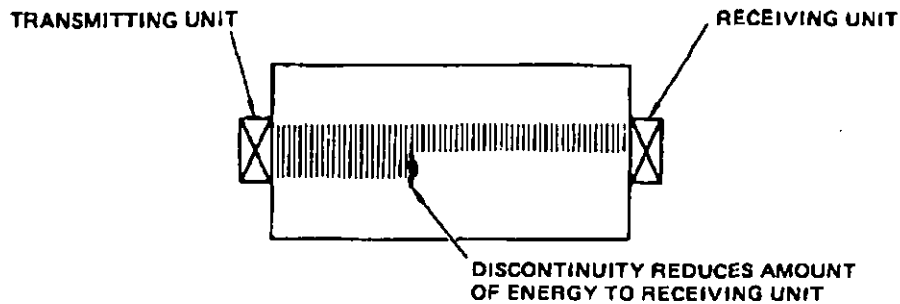OF ENERGY TO RECEIVING UNIT

Figure 6.4(9). <u>Through-transmission technique, two transducers.</u>

technique, the transmitter unit selected is the best available generator of
acoustic energy, and the receiver unit selected is the best available receiver
of ultrasonic energy. For example, a barium titanate transmitter unit is used
with a lithium sulfate receiver unit.

A variation of the through-transmission method, normally used for thin
materials, consists of a single transducer, and after the wave pulse has gone
through the material, it is reflected by a reflector and returned back to the
original transducer. In this method, an electronic gate can be used to record
the signals that come from the reflector. This essentially gives the same
information that would have been received from a second transducer if it had
been located at that point. This method reduces the number of transducers
required, and essentially is using only a one-sided type inspection.

Basically, the pulse-echo technique can provide depth information and the
through-transmission provides no depth information. In a through scan, the
entire depth of the specimen is being examined. If a material is difficult to
penetrate, the two transducer through-transmission technique can provide the
maximum penetration.

6.4.4   GENERAL TECHNIQUE CONSIDERATIONS

Ultrasonic test preparations begin with an examination of the test specimen to
determine the appropriate technique; then, components are selected from avail-
able equipment to perform the test. Many variables affect the choice of tech-
nique. For example, the test specimen may be too large to fit in the immersion
tank. In the case of large, fixed structures, the testing unit is moved to
the test site. This may require portable testing equipment. Other factors
are the number of parts to be tested, the nature of the test material, test
surface roughness, methods of joint (welded, bonded, riveted, etc.), and the
shape of the specimen. If the testing program covers a large number of
identical parts and a permanent test record is desirable, an immersion tech-
nique with automatic scanning and recording may be suitable. One-of-a-kind
or odd-lot jobs may be tested with portable contact testing units. Each case
will require some study as to the most practical, efficient technique.

When setting up any test, an operating frequency is selected, a transducer is chosen, and a reference standard is established. The test specimen is carefully studied to determine its most common or probable discontinuities. For example; in forgings, laminar discontinuities are found parallel to the forging flow lines; discontinuities in plate are usually parallel to the plate surface and elongated in the rolling direction; the common defect in pipe is a longitudinal crack, etc. If possible, a sample specimen is sectioned and subjected to metallurgical analysis.

a. Frequency Selection. Frequency is one of the most influential parameters that govern the success of ultrasonic inspection. There are a number of criteria which determine the ultrasound frequency that delivers the best sensitivity to detect flaws. These criteria include:

> Material
> Signal-to-noise ratio
> Minimum size of a flaw

The material generally determines the best ultrasound frequency. Steel usually requires 2.25 or 5.0 MHz. Aluminum generally gives best results with 5.0MHz. The way to find out which is the best frequency for the application is by trial and error. A sample part with a natural or simulated defect is obtained and scanned with ultrasonic transducers of various frequencies. The gain setting for a defect signal of common screen height provides a good indication of the most effective frequency. That is, the frequency that requires the lowest gain setting is a preferred frequency. However, the signal-to-noise ratio must also be evaluated. Ratios of the largest signal received from a minimum sized defect as compared to the largest noise signals should be at least 10 to 1 (20 db).

Spectrum analysis can ascertain which is the best frequency. Spectrum analysis is done by comparing the frequency spectrum from a natural flaw to the frequency spectrum prior to entering the material being inspected. The later spectrum can be obtained from an echo from a polished flat surface immersed in water. Spectrums which transmit much of defect information in or near the mean value of the rated transducer frequency are what is being sought. Care must be taken to compare broadband frequency with broadband and narrow band frequency with narrow band. Narrow band frequency transducers generate a more powerful pulse than broadband transducers. This is expected as broadband transducers are heavily damped to vibrate only about one and a half cycles. Higher ultrasound frequencies are neeeded for exceedingly small minimum sized defects such as are encountered in thin wall tubing inspection for nuclear reactors. Very high strength martensitic steel has a fine grain structure that can accommodate higher ultrasound frequencies with little noise.

b. Transducer Size Selection. Just as sensitivity to the presence of flaws is the reason for selecting transducer frequency, so too it is the basis for selecting size. The first question to be answered is "Do you need a focused transducer"? If the depth (thickness) of material is a centimeter or two, then a focused transducer should be considered. However, if deep or thick material is to be ultrasonically scanned, and the minimum flaw size is not miniscule, then a flat lens transducer is often the best bet.

Focused Transducers. Noise is the variable that determines the best size and configuration for a focused transducer. Small transducers with a wide beam spread and large transducers with much refraction from the large lens cause lots of noise. It is surprising how often the moderately sized transducers of about one centimeter across the lens face turn in the best performance (of least noise).

Flat Lensed Transducers. Generally, small sized transducers work best with small sized (or thickness) parts. Larger sized transducers work well for interrogation of large, deep parts. However, sensitivity falls off with increasingly larger sized transducers when the pulser is taxed to vibrate the crystal. So the power capacity of the pulser limits the size of the transducer.

Again, trial and error with evaluation of performance data reveal the best size of transducer for a particular application.

c. Reference Standards. Commercial ultrasonic reference standards are described in detail in section 6.5. These standards are adequate for many test situations, provided the acoustic properties are matched or nearly matched between the test specimen and the test block. In most cases, responses from discontinuities in the test specimen are likely to differ from the indications received from the test block hole. For this reason, a sample test specimen is sectioned, subjected to metallurgical analysis, and studied to determine the nature of the material and its discontinuities. In some cases artificial discontinuities in the form of holes or notches are introduced into the sample to serve as a basis for comparison with discontinuities found in other specimens. From these studies, an acceptance level is determined that establishes the number and magnitude (or size) of discontinuities allowed in the test specimen. In all cases, the true nature of the test material is determined by careful study of the sample specimen, and a sensible testing program is established by an intelligent application of basic theory.

6.4.5   INDICATIONS FROM VARIOUS TECHNIQUES AND THEIR INTERPRETATIONS

Ultrasonic test indications from subsurface discontinuities within the test specimen are usually related, or compared, to indications from flat-bottomed holes of varying depths or diameters in standard test blocks. These comparisons are a fair means of evaluating the size, shape, position, orientation, and impedance of discontinuities. Test conditions, and the discontinuities themselves, are sometimes the cause of ultrasonic phenomena which are difficult to interpret. This type of difficulty can only be resolved by relating the ultrasonic indications to the probable type of discontinuity with reference to the test conditions. Impedance of the material, surface roughness, surface contour, attenuation, and angle of incidence are all to be considered when evaluating the size and location of an unknown discontinuity by the amplitude of the indication received. The simplest method is to compare the indication of the discontinuity with indications from a test block similar to the test specimen in alloy, shape, and back-surface reflections. The experienced operator also learns to discriminate between the indications of actual defects and false or nonrelevant indications.

a.   Typical Immersion Test Indications

Immersion test indications, as displayed on an A-scan in a pulse-echo mode, are interpreted by analysis of three factors: the amplitude of the reflection from a discontinuity, the loss of back-surface reflection, and the distance of discontinuity from the surfaces of the article. Individual discontinuities that are small, compared with the transducer crystal diameter, are usually evaluated by comparing the amplitude of the test-specimen echoes with the test-block echoes. Since the surface of the test specimen and the surface of a discontinuity within it are not as smooth as the surface of the test block and the flat-bottomed hole in the test block, the estimated size of the discontinuity is generally a bit smaller than the actual size. Discontinuities that are larger than the crystal diameter, are evaluated by noting the distance the crystal is moved over the test specimen while an indication is still maintained. In this case, the amplitude has no quantitative meaning; the length over which the amplitude is maintained does indicate the extent of the discontinuity in one plane. A loss, or absence, of back-surface reflection is evidence that the transmitted sound has been absorbed, refracted, or reflected so that the energy has not returned to the crystal. Evaluating this loss does not always determine the size of the discontinuity as concisely as the comparison method used on small discontinuities.

When relatively large discontinuities are encountered, the discontinuity may eliminate the back-surface reflection since the beam is not transmitted through the discontinuity.

1.   Small Discontinuity Indications. A significant number of the discontinuities encountered in ultrasonic testing of wrought aluminum are relatively small. Foreign materials or porosity in the cast ingot are rolled, forged, or extruded into wafer-thin discontinuities during fabrication. The forces used in fabrication tend to orient the flat plane of the discontinuity parallel to the surface of the part. Such a

discontinuity and its ultrasonic indication are shown in Figure 6.4(10). The
relationship of the discontinuity indication and its amplitude is determined
by comparison with a range of test block flat-bottomed hole reflections, as
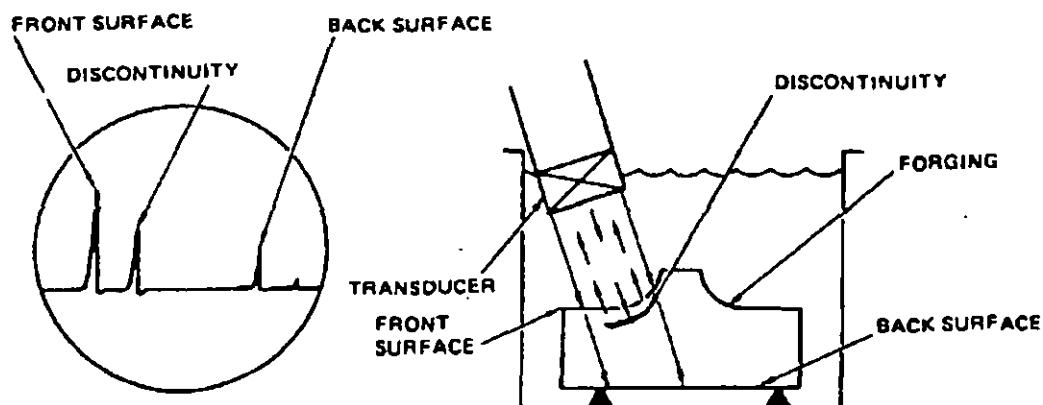shown in Figure 6.4(11).

Figure 6.4(10). Force-oriented discontinuity indication.

2. **Large Discontinuity Indications.** Discontinuities that are large, when
compared with the crystal size, usually produce a display, as shown in
Figure 6.4(12). Since the discontinuity reflects nearly all of the
ultrasonic energy, the partial or total loss of back-surface reflection is
typical. The dimensions of the discontinuity may be determined by
measuring the distance that the transducer is moved while still receiving
an indication. If the discontinuity is not flat, but is three-dimensional,
the extent of the third dimension may be determined by turning the article
over and scanning from the back side. If the possibility of two
discontinuities lying close together is suspected, the article may be
tested from all four sides.

3. **Loss of Back-Surface Reflection.** Evaluating the loss of back-surface
reflection is most important when it occurs in the absence of significant
individual discontinuities. In this case, among the causes of reduction,
or loss, of back-surface reflection are large grain size, porosity, and a
dispersion of very fine precipitate particles. Figure 6.4(13) shows the
indications received from a sound test specimen and the indications
displayed from a porous specimen. Note that the back-surface reflections
obtained from the porous specimen are reduced considerably.

4. **Nonrelevant Indications.** When considering indications that may be
nonrelevant, it is a good rule to be suspicious of all indications that
are unusually consistent in amplitude and appearance while the transducer
is passing over the test specimen. Reflections from fillets and concave
surfaces may result in responses appearing between the front and back
surfaces. These are sometimes mistaken for reflections from
discontinuities. Reflections from a contoured surface may be shielded off
by interrupting the beam with a foreign object such as a piece of sheet
metal, as shown in Figure 6.4(14). Broad-based pips, as contrasted to a
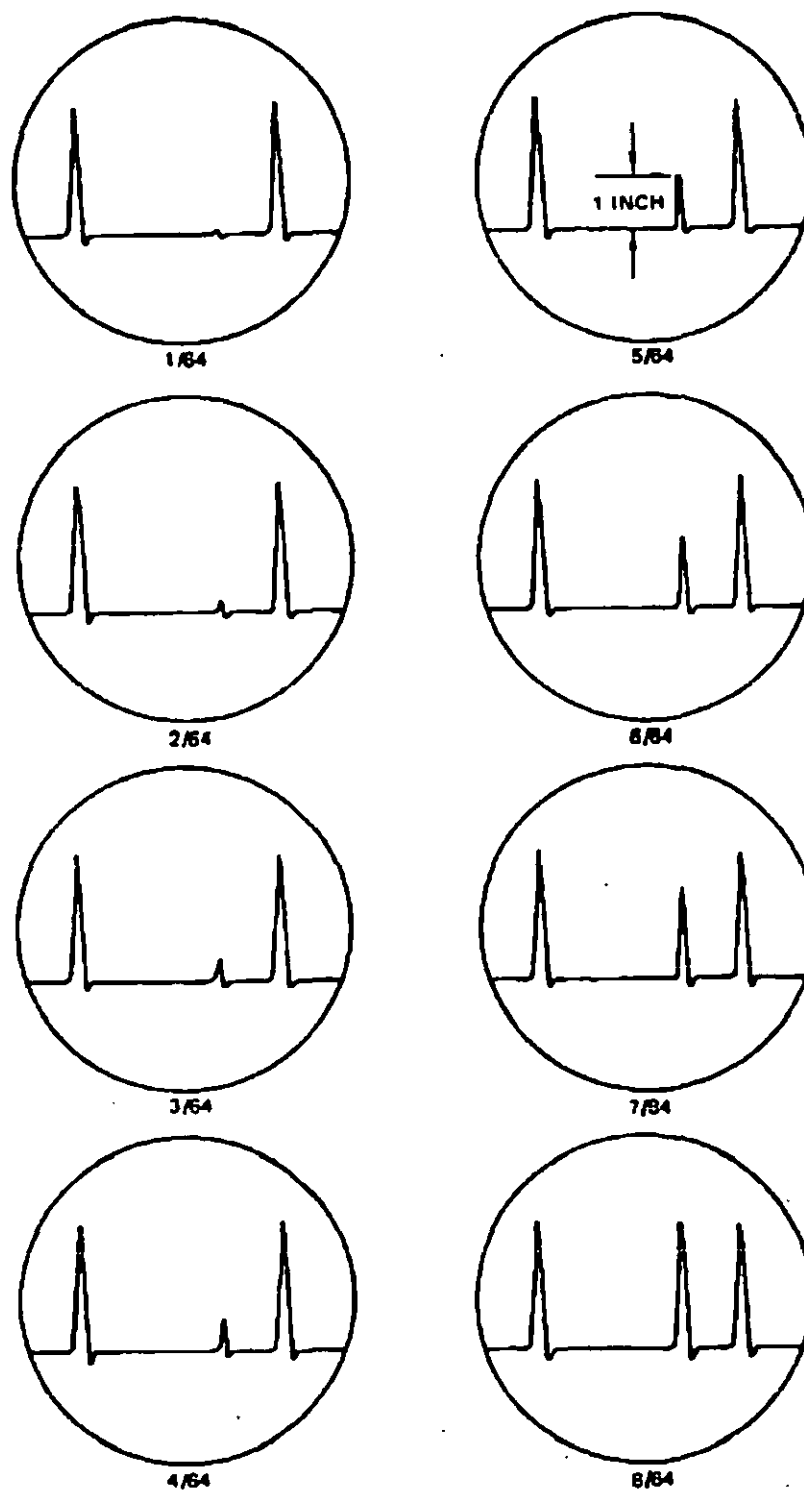sharp spike or pip, are likely to be re.lections from a contoured surface.

Figure 6.4(11). <u>Amplitude range of 1/64 to 8/64 flat-bottomed holes.</u>
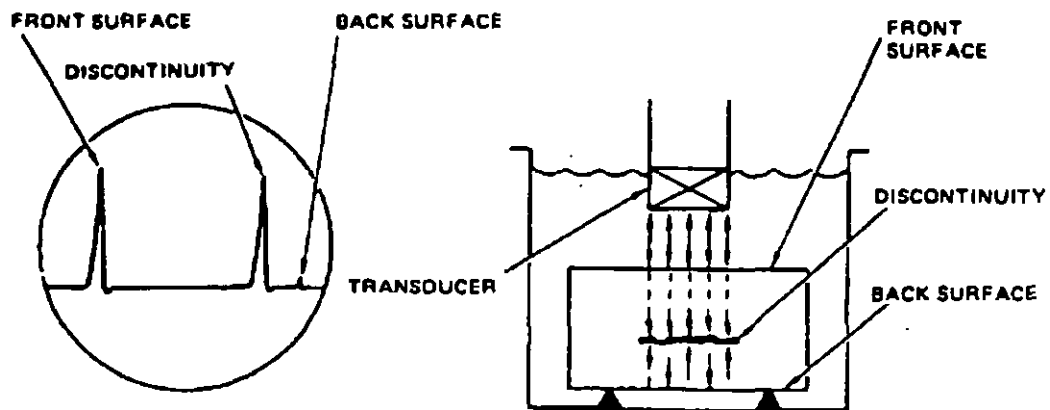
Figure 6.4(12).   Large discontinuity indication.
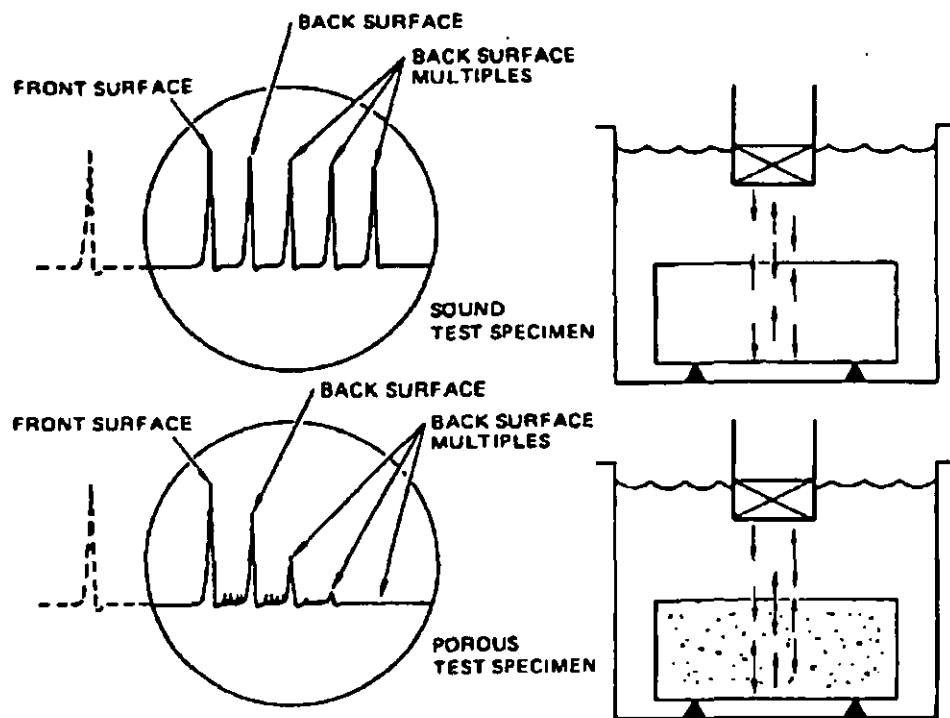

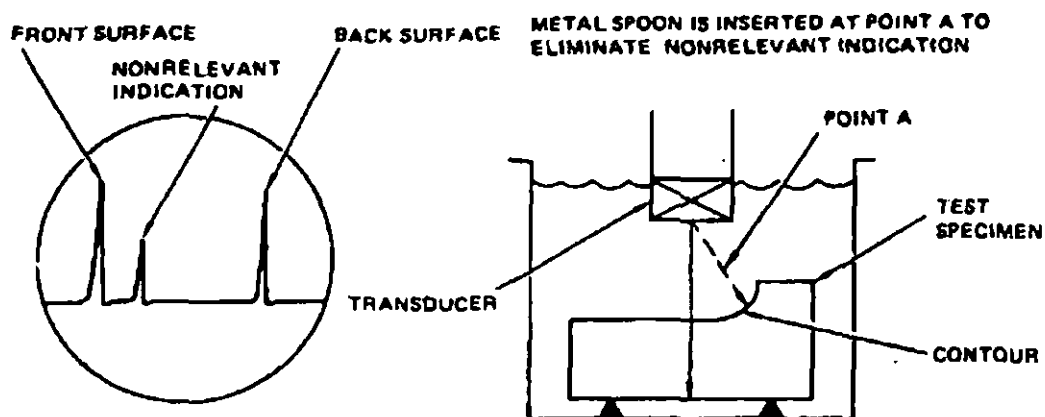Figure 6.4(13).   Reduced back reflection from porosity.

Figure 6.4(14). Nonrelevant indication from contoured surface.

Near the edges of rectangular shapes, edge reflections are sometimes observed with no loss of back-surface reflection. This type of indication usually occurs when the transducer is within 1/2-inch of the edge of the part.

Articles with smooth, shiny surfaces will sometimes give rise to false indications. For example, with a thick aluminum plate machined to a smooth finish, spurious indications which appeared to be reflections from a discontinuity located at about one-third of the article depth were received. As the transducer was moved over the surface of the plate, the indication remained relatively uniform in shape and magnitude. Apparently this type of indication results from surface waves generated on the extremely smooth surface, and possibly reflected from a nearby edge. They are eliminated by coating the surface with wax crayon or a very thin film of petroleum jelly.

5. Angled-Plane Discontinuity Indications. Discontinuities oriented with their principal plane at an angle to the front surface are sometimes difficult to detect and evaluate. Usually, it is best to scan initially at a comparatively high gain setting to detect angled-plane discontinuities. Later the transducer is manipulated around the area of the discontinuity to evaluate its magnitude. In this case, the manipulation is intended to cause the beam to strike the discontinuity at right angles to its principal plane. With large discontinuities that have a relatively flat, smooth surface but lie at an angle to the surface, the indication moves along the base line of the display as the transducer is moved because of the change in distance of beam travel. Bursts in large forgings fit this category; they tend to lie at an angle of 45 degrees to the surface.

6. <u>Grain Size Indications</u>. Unusually large grain size in the test specimen may produce "hash," or noise, indications, as shown in Figure 6.4(15). In the same illustration, note the clear indications received from the same type of material with fine grain. In some cases, abnormally large grain-size results in a total loss of back-surface reflection. These conditions are usually brought about by prolonged or improper forging temperatures, or high temperature during hot working and subsequent improper annealing of the test specimen.

FRONT SURFACE   BACK SURFACE

FINE-GRAIN
STEEL

(FROM PHOTO-
MICROGRAPHS)

FRONT SURFACE   "HASH"

BACK
SURFACE

COARSE-GRAIN
STEEL
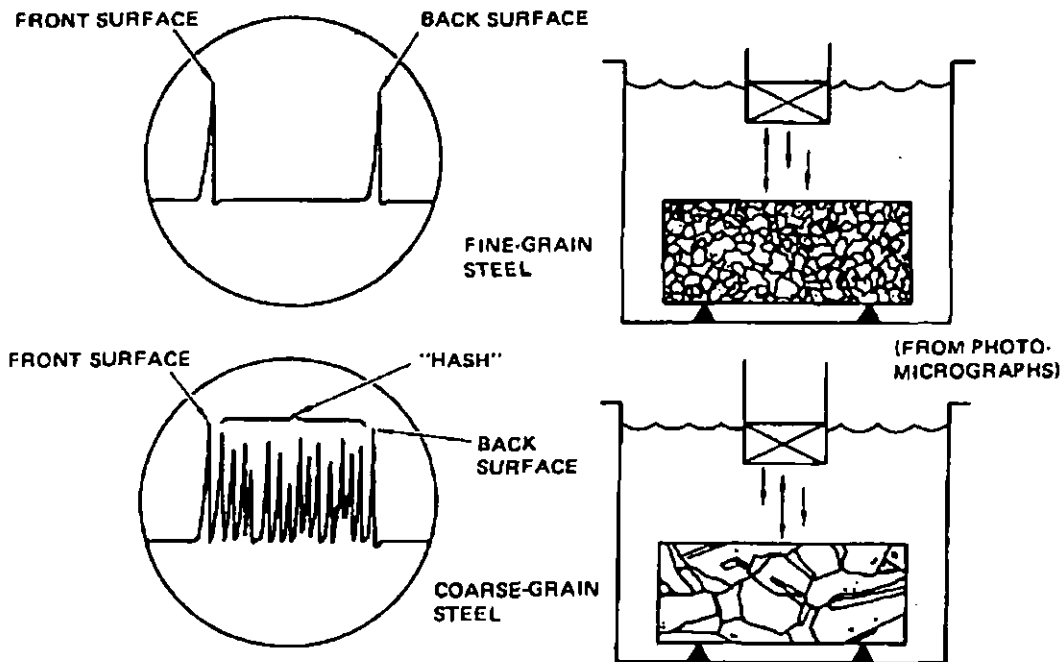
Figure 6.4(15).   <u>Grain size locations</u>.

b. <u>Typical Contact Test Indications</u>

Contact test indications, in many instances, are similar or identical to those discussed in the previous paragraphs on immersion test indications. Little additional discussion will be given when contact indications are similar to immersion indications. Interference from the initial pulse at the front surface of the test specimen and variations in efficiency of coupling, produce nonrelevant effects that are sometimes difficult to recognize in contact testing. As in immersion testing, signal amplitude, loss of back reflection, and distance of the discontinuity from the surfaces of the article are all major factors used in evaluation of the display.

1.   **Typical Discontinuity Indications.** Typical indications encountered in ultrasonic testing include those from discontinuities such as nonmetallic inclusions, seams, forging bursts, cracks, and flaking found in forgings, as shown in Figure 6.4(16).
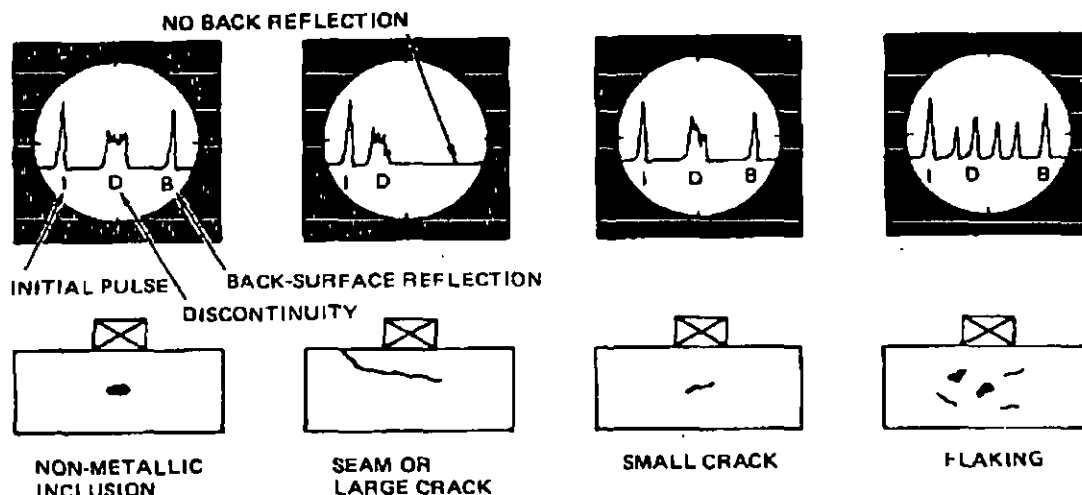
NO BACK REFLECTION

INITIAL PULSE   BACK-SURFACE REFLECTION

DISCONTINUITY

NON-METALLIC   SEAM OR   SMALL CRACK   FLAKING
INCLUSION   LARGE CRACK

Figure 6.4(16).   **Typical contact test discontinuity indications.**

Delaminations in rolled sheet and plate are shown by a reduction in the distance between back-surface reflection multiples, as shown in Figure 6.4(17). View A illustrates the display received from a normal plate and view B shows the back-surface reflections received when the transducer is moved over the delamination.

In angle-beam testing of welds, a satisfactory weld area is shown with the weld fusion zones clearly indicated as shown in view A of Figure 6.4(18). View B shows the same reflections for the fusion zones, but in this case, a discontinuity is located in the center of the weld. The weld seam commonly has discontinuities such as porosity and slag that produce indications as shown in Figure 6.4(19).

Surface cracks are sometimes detected when testing with a shear wave produced by an angle-beam transducer. Figure 6.4(20) shows a surface-wave indication from a crack in the surface of the test specimen.
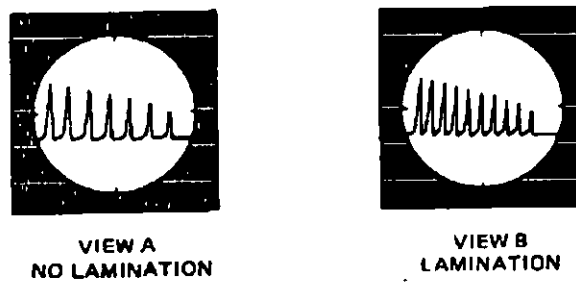
VIEW A
NO LAMINATION

VIEW B
LAMINATION

Figure 6.4(17). <u>Effect of delamination on back-surface reflection multiples.</u>

WELD

NEAR EDGE

DISCONTINUITY

FAR EDGE

A

B
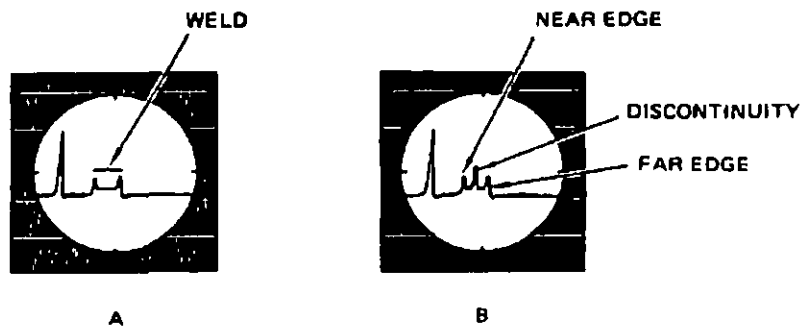
Figure 6.4(18). <u>Weld indications using angle-beam contact techniques.</u>
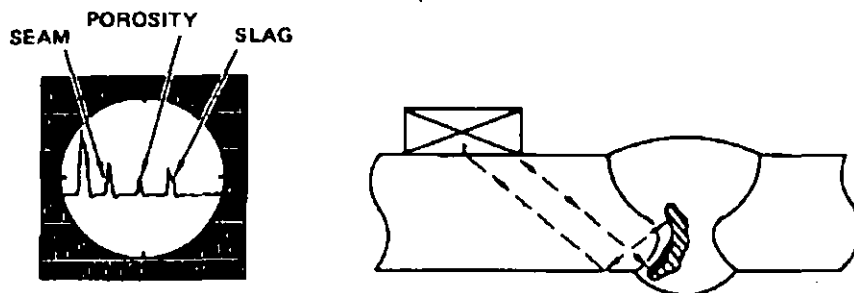
SEAM   POROSITY   SLAG

Figure 6.4(19). <u>Porosity and slag indications in weld seam.</u>
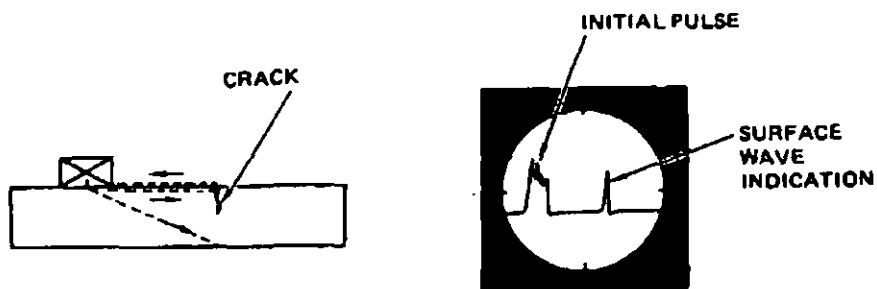
Figure 6.4(20). Surface crack indication using angle-beam technique.

With pitch-and-catch testing, using two transducers, the initial, or transmitted, pulse does not interfere with reception, as it does when using the single transducer. Figure 6.4(21) shows the indications received from a relatively thin, test specimen using two transducers. Paired angle-beam transducers are used to improve near-surface resolution. The transit time of the soundbeam when passing through the Lucite wedge on which the transducers are mounted gives an additional advantage in that the initial pulse is moved to the left in the same way the water-path separation occurs in immersion testing.

A serious problem with pitch-and-catch testing is changes in coupling efficiency. Unless a back echo is monitored, there is no way to know that coupling efficiency is changing or that the coupling is lost. This is why pitch and catch testing is not popular.

Figure 6.4(22) shows an indication from a discontinuity which lies only 0.02 inch below the surface of the material. Often, the best way to detect the presence of flaws just below the front surface is to first bounce off the back surface and then monitor.
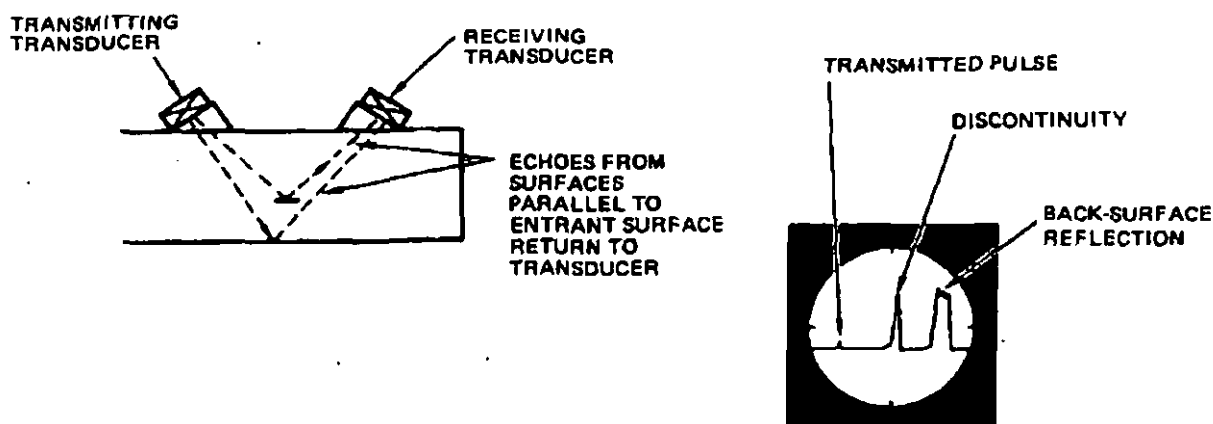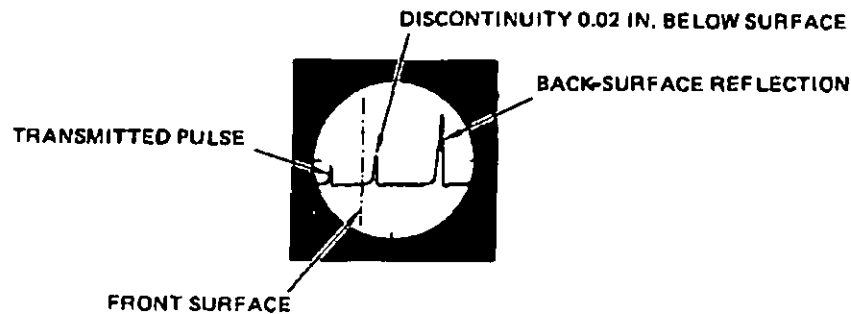

Figure 6.4(21). Two-transducer indications.

DISCONTINUITY 0.02 IN. BELOW SURFACE

BACK-SURFACE REFLECTION

TRANSMITTED PULSE

FRONT SURFACE

Figure 6.4(22). Indication of near-surface discontinuity.

2. **Dead-Zone Indications.** A dead zone exists directly beneath the front surface from which no reflections are displayed because of obstruction by the initial pulse. In most contact testing, the initial pulse obscures the front-surface indications as shown in Figure 6.4(23). Near-surface discontinuities may be difficult to detect with straight-beam transducers, because of the initial-pulse interference. Shortening the initial pulse may be effective when near-surface discontinuities are obscured by the ringing "tail" of the initial pulse. Figure 6.4(24) shows a comparison of long narrow band and short pulses broadband applied to the test specimen where the discontinuity is near the surface. In immersion testing, the initial pulse is separated from the front-surface pip by the water path. Only by inserting a standoff, such as a plastic block, can separation of these responses be achieved in contact testing. The material in the dead zone can be ultrasonically interrogated after bouncing off back surface.
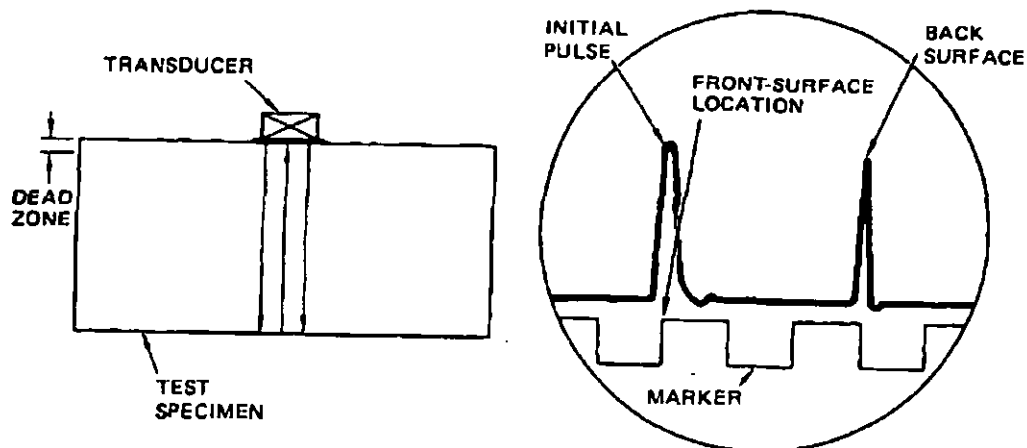
TRANSDUCER

DEAD ZONE

TEST SPECIMEN

INITIAL PULSE

BACK SURFACE

FRONT-SURFACE LOCATION

MARKER

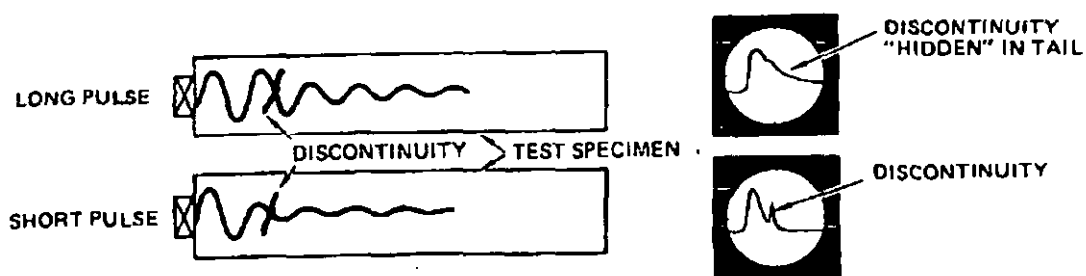Figure 6.4(23). Dead-zone interference.

6.4-19

Figure 6.4(24). Long and short pulse effects on display.

3. Nonrelevant Indications. Coarse-grained material causes reflections or "hash" across the width of the display as shown in Figure 6.4(25), when the test is attempted at a high frequency. To eliminate or reduce the effect of these unwanted reflections, lower the frequency or change the direction of the beam by using an angle-beam transducer.

Figure 6.4(25). Coarse grain indications.

When testing cylindrical specimens (especially when the face of the transducer is not curved to fit the test surface), additional pips following the back-surface echo will appear as shown in Figure 6.4(26).

In testing long specimens, mode conversion occurs from the soundbeam striking the sides of the test specimen and returning as reflected shear waves as shown in Figure 6.4(27). Changing to a larger diameter transducer will lessen this problem.

Surface waves generated during straight-beam testing also cause unwanted nonrelevant indications when they reflect from the edge of the test specimen as shown in Figure 6.4(28). This type of nonrelevant indication is easily identified since movement of the transducer will cause the indication from the surface wave to move across the display with the movement of the transducer. When testing with two angle-beam transducers, it is possible to have a small surface-wave component of the soundbeam transmitted to the receiving unit as shown in Figure 6.4(29). This type of unwanted reflection is easily recognized by varying the distance between the transducers and watching the indication; when the distance is increased, the apparent discontinuity indication moves away from the initial pulse.
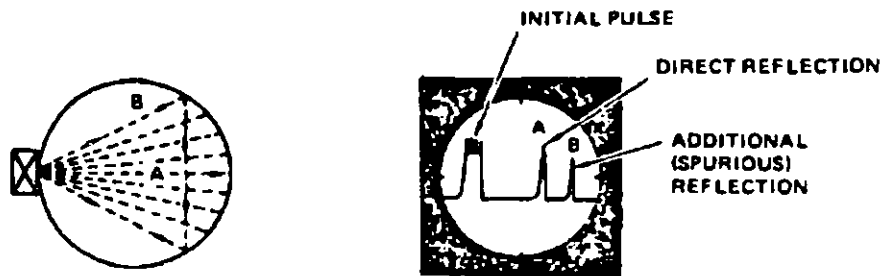
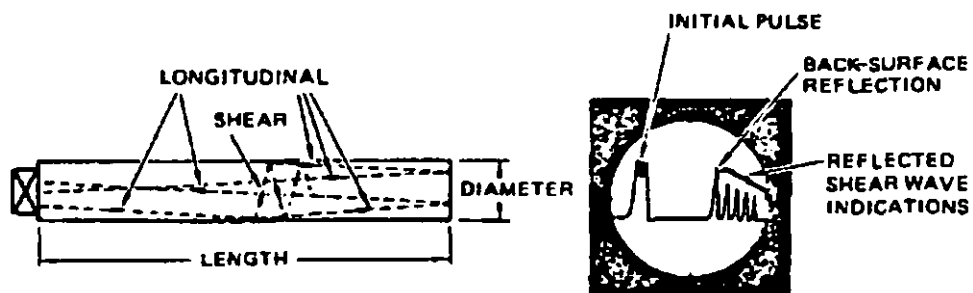**Figure 6.4(26).** **Nonrelevant indication from cylindrical specimen.**

Figure 6.4(27). **Nonrelevant indication from long bar specimen.**
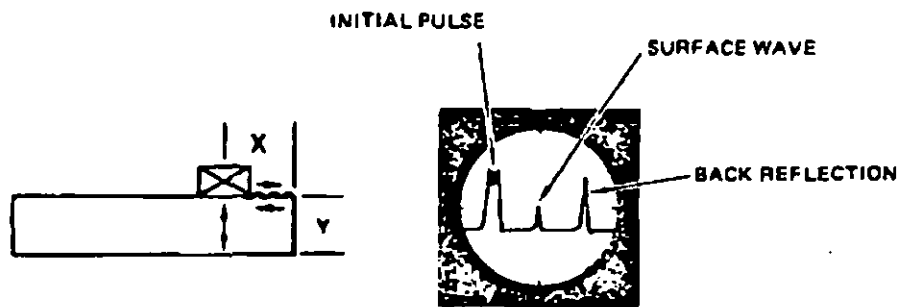

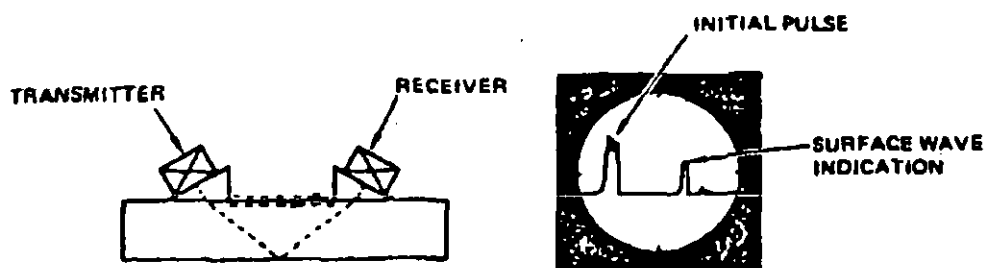**Figure 6.4(28).** **Nonrelevant surface-wave edge reflection.**

Figure 6.4(29). Nonrelevant surface-wave indication with two transducers.

When using angle-beam transducers, a certain amount of unwanted reflections are received from the wedge. These indications appear immediately following the initial pulse as shown in Figure 6.4(30). The reflections from within the wedge are easily identified because they are still present on the display when the transducer is lifted off the test specimen.

With continued use, the crystal in the transducer may come loose or fracture. When this happens, the indication is characterized by a prolonged ringing which adds a "tail" to the initial pulse as shown in Figure 6.4(31). As the prolonged ringing effect results in a reduced capability of the system to detect discontinuities, the transducer is discarded or repaired.
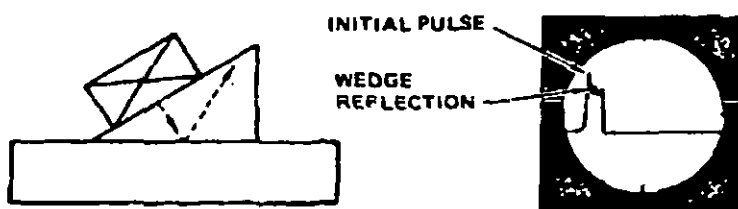

Figure 6.4(30). Nonrelevant indication from plastic wedge.

A   B

Figure 6.4(31). Nonrelevant indication from loose transducer crystal.

6.4.6 NEWEST PROCEDURES AND TECHNIQUES

For many years, several new methods of ultrasonic testing have been developed. Detailed discussions of these new methods will not be presented, but brief descriptions will be given.

6.4.6.1 Acoustic Emissions

Acoustic emissions is an ultrasonic test method. However, no active search beam or other external ultrasonic energy source is used. Acoustic emissions use transducers that detect ultrasonic pulses that are produced within the material. Normally, these pulses are produced because of induced stresses within the material, and are caused by localized displacements that result from these stresses. Therefore, acoustic emissions must normally be used in conjunction with some other test where changes in temperatures or loads are producing stresses and strains within the material. By triangulation, the location of the sources of these pulses can usually be determined; and by analyzing their relative magnitudes or other characteristics, the nature of the source can sometimes be characterized. Some basic requirements of acoustic emissions are: first, the nature of the material must be such that ultrasonic pulses are produced. This seems to be common for most materials, especially where internal defects are present, which are especially prone to the generation of mechanical slippages and dislocations. Second, the material must adequately transmit the ultrasonic energy from the source to the transducers. Third, external noise from test apparatus or other sources must be separable from the sources within the material. Last of all, some correlation or other meaning must be developed with the characteristics of the signals unless location or time correlations are the only parameters of interest.

Since some of these requirements are not always met, acoustic emissions is not always successful. There are many situations, however, where acoustic emission testing is the most useful or the only possible method. Today, the testing of arm booms made of composite materials and nuclear pressure vessels are extensively done with acoustic emissions.

One of the greatest problems with acoustic emissions is the detection system. Present day acoustic emission transducers do not in general record the true fidelity of the internal ultrasonic pulses, but merely ring at their own natural frequency. Therefore, scientific correlations between the detected signal and the source are limited.

6.4.6.2 Resonance or Acousto-Ultrasonics

Many ultrasonic testing devices inject ultrasonic energy into a part and measure the changes produced in the standing waves or reflections established within or between the material and the transducer. In some cases, these changes include both phase and amplitude parameters. These test methods do not normally "image" a defect or other variable, but usually reflect the total

response of the test region. Because the response is a general response, it is capable of easy interpretation, but for the same reason, it cannot always provide the details that may be desired. In acousto-ultrasonics, changes in the injected ultrasonic signal, as it travels from one transducer to another, are used as a correlation parameter. Again, no "imaging" of defects is produced by these test methods, but they can often generalize the material in such a way that very effective test measurements are established.

6.4.6.3 Scanning Laser Acoustic Microscope (SLAM)

This method uses high frequency (30 to 500 MHz) ultrasonic waves that are transmitted through a specimen to an image plane. The image plane can be the surface of the specimen or any light reflective surface acoustically connected to the specimen. The ultrasonic waves extend over the entire image area and form a pattern on the image plane that is a function of the acoustic variables within the imaged area. This pattern is detected by a scanning laser beam and displayed in real time on a CRT screen. Because of the high frequencies, very small variables can be detected, as small as 5μm, at the 500 MHz range. However, the penetration depth is also limited by the high frequency, and thus this method is fairly limited to small specimens.

6.4.6.4 Ultrasonic Holography

Ultrasonic holography is another real time inspection system which uses a laser beam to detect an ultrasonic hologram formed on a liquid surface. The ultrasonic hologram is formed by the interference of two ultrasonic beams, one of which has been transmitted through the specimen. Adaptations of this method presently include methods that allow electrical signal references and nonimmersion techniques.

(WP ID# 6595A/DISK 0282A. FOR AMMRC USE ONLY)

6.5 STANDARDS

In ultrasonic testing, discontinuity indications are normally compared to
indications received from testing a reference standard. The reference
standard may be any one of many reference blocks, or sets of blocks, specified
for a given test or it may be an actual part to be tested containing a known
natural or simulated flaw. Standards made from such parts are hard to beat in
production. When standards can be used to check the accuracy of the
ultrasonic inspection, just feed the standard into the test equipment.
Observe that it is rejected, and remove the standard from the production
line. Extreme caution must be exercised to remove the part or parts from the
production line. In comparison, ultrasonic standard reference blocks are more
useful in a laboratory. Reference blocks are flexible but slow in use.

Ultrasonic standard reference blocks, often called test blocks, are used in
ultrasonic testing to standardize the ultrasonic equipment and to evaluate the
discontinuity indication received from the test part. Standardizing does two
things: it verifies that the instrument/transducer combination is performing
as required; it establishes a sensitivity, or gain setting at which all
discontinuities of the size specified, or larger, will be detected.
Evaluation of discontinuities within the test specimen is accomplished by
comparing their indications with the indication received from an artificial
discontinuity of known size, and at the same depth, in a standard reference
block of the same material.

Standard test blocks are made from carefully selected ultrasonically inspected
stock that meets predetermined standard of ultrasonic attenuation, grain size,
and heat treat. Discontinuities are represented by carefully drilled
flat-bottomed holes. Test blocks are made and tested with painstaking care so
that the only discontinuity present is the one that was added intentionally.
The three most familiar sets of reference blocks are the Alcoa-Series A, area
amplitude blocks; the Alcoa-Series B, or Hitt, distance/amplitude blocks; and
the ASTM basic set of blocks that combine area/amplitude and distance/amplitude
blocks in one set.

6.5.1 AREA/AMPLITUDE BLOCKS SET

The Alcoa Series A set consists of eight blocks, each 3-3/4-inches long and
1-15/16-inches square. A 3/4-inch deep, flat-bottomed hole (FBH) is drilled
in the bottom center of each block. The hole diameters are 1/64-inch in the
No. 1 block through 8/64-inch in the No. 8 block, as shown in Figure 6.5(1).
As implied, the block numbers refer to the FBH diameter; e.g., a No. 3 block
has a 3/64-inch diameter FBH.

Area/amplitude blocks provide a means of checking the linearity of the test
system; that is, they confirm that the amplitude (height) of the indication on
the oscilloscope screen increases in proportion to the increase in size of the
discontinuity. Similar area/amplitude reference blocks are made from 2-inch
diameter round stock.

6.5.2   DISTANCE/AMPLITUDE BLOCKS SET

The set of Alcoa Series B, or Hitt, blocks consists of nineteen, 2-inch diameter, cylindrical blocks, all with 3/4-inch deep FBH of the same diameter drilled in the center at one end. These blocks are of different lengths to provide metal distances of 1/16-inch to 5-3/4 inches from the test surface to the FBH. Sets with 3/64-, 5/64-, or 8/64-inch diameter holes are available. The metal distances in each set are 1/16-inch, 1/8-inch through 1-inch in eighth-inch increments, and 1-1/4 inch through 5-3/4 inch in half-inch increments, as shown in Figure 6.5(2).

Distance/amplitude blocks serve as a reference by which the size of discontinuities at varying depths within the test material may be evaluated. They also serve as a reference for setting or standardizing the sensitivity, or gain, of the test system so that the system will display readable indications on the oscilloscope screen for all discontinuities of a given size and over, but will not flood the screen with indications of smaller discontinuities that are of no interest. On instruments so equipped, these blocks are used to set the sensitivity time control (STC) or distance amplitude correction (DAC) so that a discontinuity of a given size will produce an indication of the same amplitude on the oscilloscope screen regardless of its distance from the front surface.
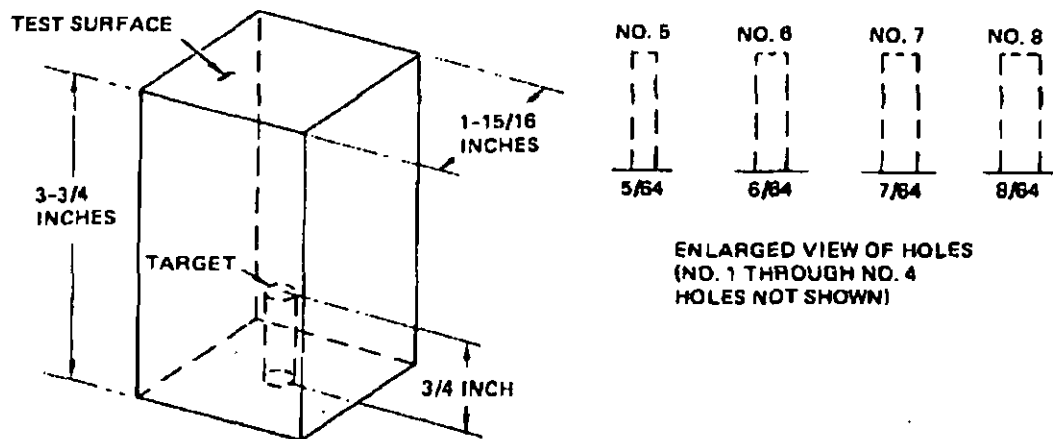
Figure 6.5(1). **Area/amplitude reference blocks.**
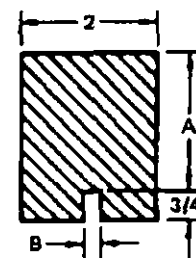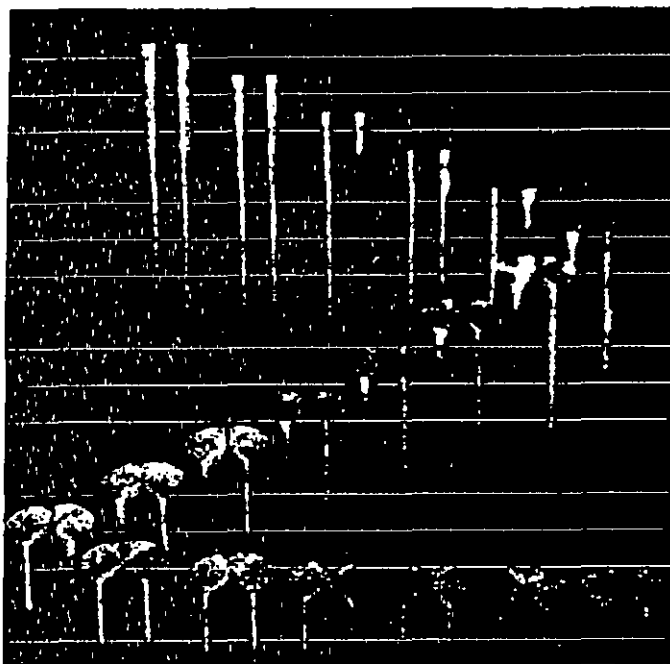
Figure 6.5(2). **Distance/amplitude reference blocks (Hitt).**

6.5.3   BASIC BLOCKS SET

The ASTM basic set shown on Figure 6.5(3) consists of ten, 2-inch diameter blocks that have 3/4-inch deep, FBH drilled in the center at one end. One block has a 3/64-inch diameter FBH and a metal distance of 3 inches from the test surface to the FBH. The next seven blocks each have a 5/64-inch FBH but metal distances are 1/8, 1/4, 1/2, 3/4, 1-1/2, 3, and 6 inches from the test surface to the FBH. The two remaining blocks each have an 8/64-inch diameter FBH and metal distances of 3 inches and 6 inches. In this basic set, the three No. 3, 5, and 8 blocks with the 3-inch metal distance, provide the area/amplitude relationship, and the seven blocks with the 5/64-inch diameter FBH (No. 5) and varying metal distances, provide the distance/amplitude relationship.
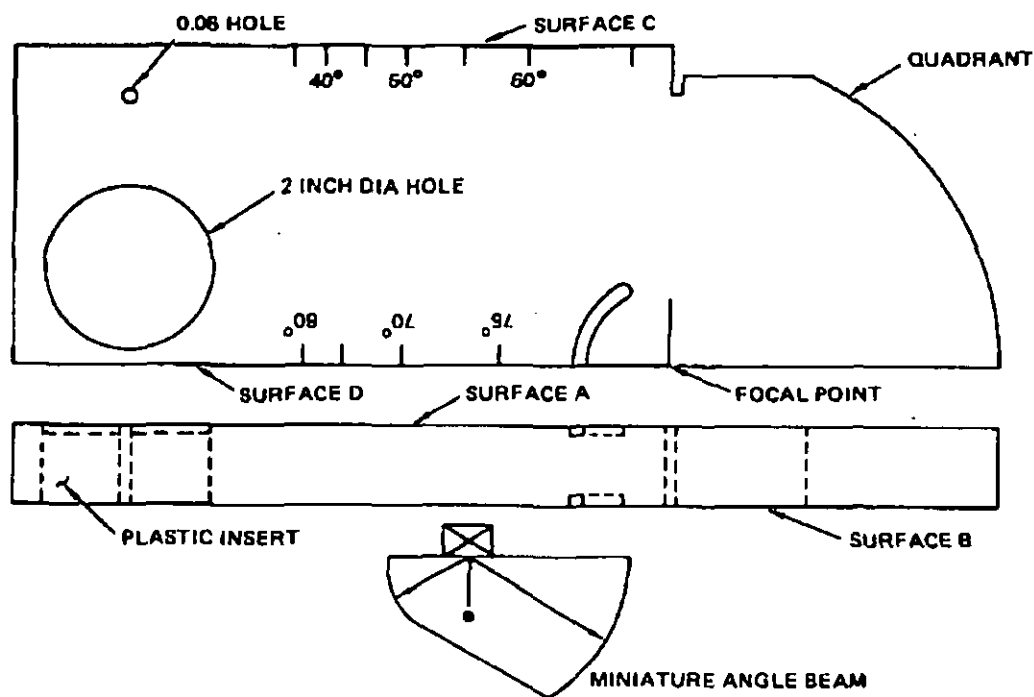
It is important that the test block material be the same, or similar to, that of the test specimen. Alloy content, heat treatment, degree of hot or cold working from forging, rolling, etc., all affect the acoustical properties of the material. If test blocks of identical material are not available, they must be similar in ultrasonic attenuation, velocity, and impedance.

6.5.4   SPECIAL BLOCKS

The International Institute of Welding (IIW) reference block and the miniature angle beam field calibration block, shown in Figure 6.5(4) are examples of other reference standards in common use.

For irregularly shaped articles, it is often necessary to make one of the test articles into a reference standard by adding artificial discontinuities in the form of flat-bottomed holes, saw cuts, notches, etc. In some cases, these artificial discontinuities can be placed so that they will be removed by subsequent machining of the article. In other cases, a special individual standardizing technique is developed by carefully studying an article ultrasonically, and then verifying the detection of discontinuities in the article, by destructive investigation. The results of the study then become the basis for the testing standard.

METAL DISTANCE, INCHES	1/8	1/4	1/2	3/4	1-1/2	.3	3	3	6	6
FBH DIA IN 64THS INCH	5	5	5	5	5	3	5	8	5	8
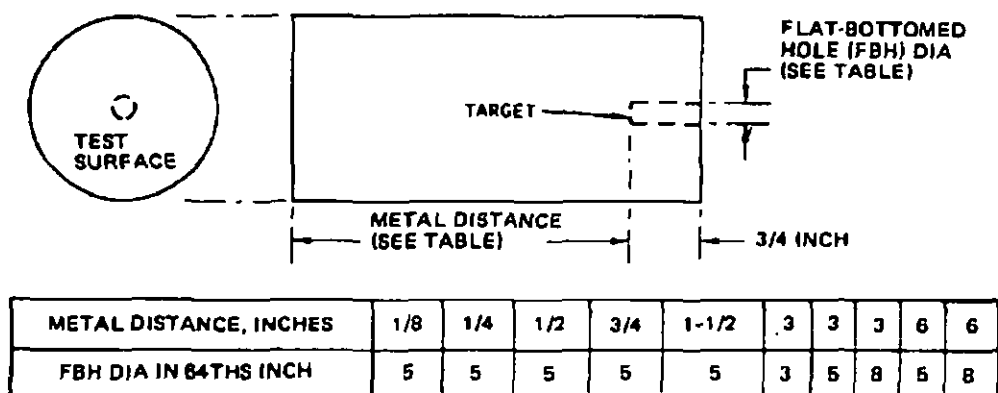
Figure 6.5(3). ASTM reference blocks, basic set.

Figure 6.5(4). Special reference blocks.

6.5.5   TYPICAL CALIBRATION PROCEDURE

A typical calibration procedure is outlined in the paragraphs that follow.
The procedures assume conditions and equipment as follows:

a. Test Instrument. Any of several commercially available pulse-echo
ultrasonic testing instruments.

b. Test Frequency. The test frequency shall be 15 MHz.

c. Transducer. A quartz immersion transducer of 3/8-inch diameter with an
operational frequency of 15 MHz.

d. Power Source. Line voltage with regulation ensured by a voltage
regulating transformer.

e. Immersion Tank. Any container that holds couplant and is large enough to
allow accurate positioning of the transducer and the reference block is
satisfactory.

f. Couplant. Clean deaerated water is used as a couplant. The same water,
at the same temperature, is used when comparing the responses from differing
reference blocks.

g. Bridge and Manipulator. The bridge is strong enough to support the
manipulator and rigid enough to allow smooth, accurate positioning of the
transducer. The manipulator adequately supports the transducer and provides
fine angular adjustment in two vertical planes normal to each other.

h. Reference Blocks. An area/amplitude set and a distance/amplitude set of
reference blocks are required. (A basic set which combines both area and
distance responses may be used; for example, the ASTM basic set consisting of
ten reference blocks. For area/amplitude relationships use blocks containing
a 3-inch metal distance and 3/64-, 5/64-, and 8/64-inch diameter holes. For
distance/amplitude relationships use blocks of varying length which contain
5/64-inch diameter holes.)

i. Fundamental Reference Standard. When calibrating area/amplitude responses
of the test set, an alternate to the reference blocks described in the
preceding step is a set of 15 steel balls, free of corrosion and surface marks
and of ball-bearing quality, ranging in size from 1/8- to 1-inch diameter in
1/16-inch increments. A suitable device, such as a tee pin, is necessary to
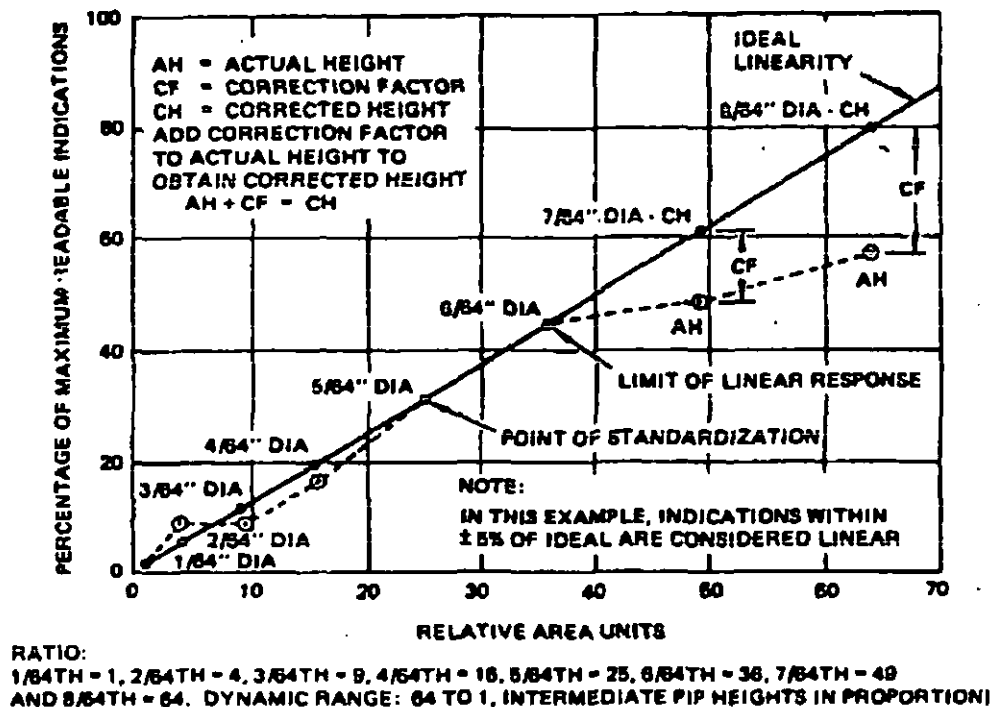hold each ball.

Area/Amplitude Check

The linear range of the instrument is determined by obtaining the ultrasonic responses from each of the area/amplitude-type reference blocks (the steel balls may be used as an alternate for the reference blocks) as follows.

a. Place a No. 5 area/amplitude reference block (a block containing a 5/64-inch diameter hole) in the immersion tank with the drilled hole down. Position the transducer over the upper surface of the block, slightly off-center, at a water distance of 3 inches within a + or - tolerance of 1/32-inch, between the face of the crystal and the surface of the block. This accurate distance is obtained by using a gage between the block and the transducer

b. Adjust the transducer with the manipulator to obtain a maximum pip height from the front-surface reflection of the block. This indication proves that the soundbeam is perpendicular to the top surface of the block. A maximum number of back-surface reflection pips serves the same purpose.

c. Move the transducer laterally until the maximum response is received from the FBH.

d. Adjust the instrument gain control until the hole pip height is 31 percent of the maximum obtainable on the cathode ray tube screen. Do not repeat this step for the remaining blocks in the set.

e. Replace that reference block with each of the other blocks in the set. Repeat steps b and c for each block and record the indications. Maintain a water distance of 3 inches for each block except for the No. 7 and No. 8 blocks, which require a water distance of 6 inches.

f. Plot a curve of the recorded indications as shown in Figure 6.5(5). In the example shown, the point where the curve of responses deviates from a straight line defines the limit of linearity in the instrument. Amplitudes plotted below the limit of linear response (in this example) are in the linear range of the instrument and no correction is required. Amplitudes of indications above the limiting point are in the non-linear range and are increased to the ideal linearity curve. This is done by projecting a vertical line upward from the actual height of indication until the ideal curve is intercepted. The point of interception defines the corrected height (CH) of indication in percent of maximum amplitude that the instrument can display. The difference between the corrected height (CH) and the actual height (AH) is the correction factor (CF). For each indication that appears in the non-linear range a different correction factor (CF) is plotted because the deviation is not constant. When the actual indication height is displayed, the corrected indication height is computed by adding the correction factor directly to the actual indication height as follows:

$$AH + CF = CH$$

RATIO:
1/64TH = 1, 2/64TH = 4, 3/64TH = 9, 4/64TH = 16, 5/64TH = 25, 6/64TH = 36, 7/64TH = 49
AND 8/64TH = 64. DYNAMIC RANGE: 64 TO 1, INTERMEDIATE PIP HEIGHTS IN PROPORTION!

Figure 6.5(5). Typical area/amplitude response curve.

g. The linear range of the instrument may also be determined by recording the
ultrasonic responses from the back-surface of each of 15 steel balls ranging
in size from 1/8- to 1.0-inch in diameter in 1/16-inch increments. The
immersion method is used following previous steps a through f, except that in
step d, the instrument gain control is adjusted until the pip height is 50% of
the maximum obtainable on the oscilloscope screen with the transducer
positioned over the 1/2-inch diameter steel ball. For each ball, the water
distance is maintained constant at 3 ± 1/32 inch and the transducer is
positioned for maximum response from each ball. The recorded indications are
plotted on a curve as shown in Figure 6.5(6).

Distance/Amplitude Check

The distance/amplitude characteristics of the instrument are determined by
obtaining the ultrasonic responses from each of the reference blocks in a set
of blocks of varying metal distance with a 5/64-inch diameter hole in each
block. The resultant indications are recorded on a curve as outlined in the
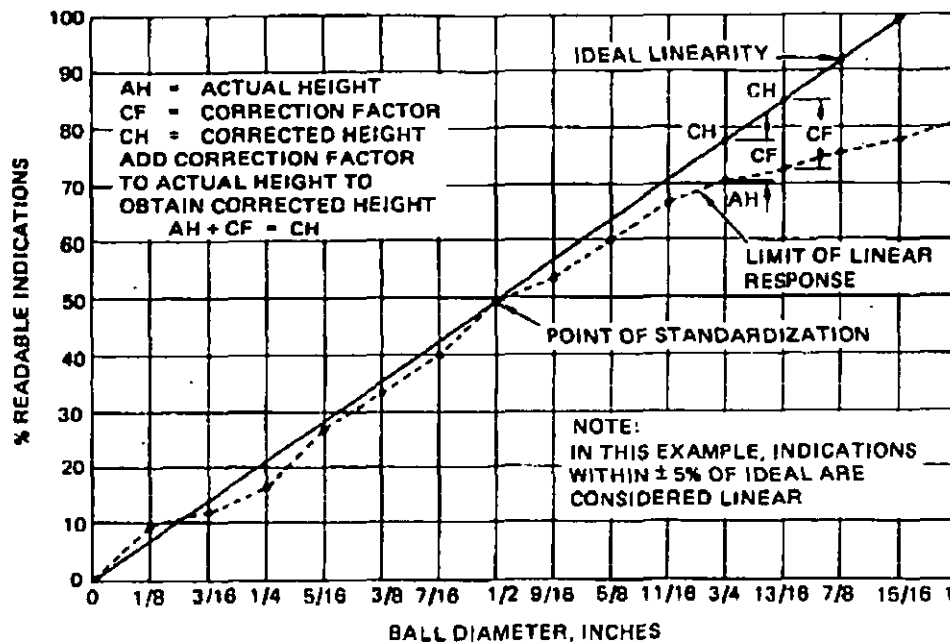following procedure.

MIL-HDBK-728/6

Figure 6.5(6). Steel ball area/amplitude response curve.

a. Select a reference block containing a 5/64-inch FBH hole with a metal distance of 3.000 inches from the top surface to the hole bottom and place it in the immersion tank. Position the transducer over the upper surface of the block, slightly off-center, at a water distance of 3 inches between the face of the transducer and the surface of the block. Adjust this distance accurately, within a + or - tolerance of 1/32 inch, by using a gage between the block and the transducer.

b. Adjust the transducer with the manipulator to obtain a maximum pip height from the front-surface reflection of the block. This indication proves that the soundbeam is perpendicular to the top surface of the block. A maximum number of back-surface reflections serves the same purpose.

c. Move the transducer laterally until the maximum response is received from the FBH. Adjust the instrument gain control until the pip height is 25% of the maximum obtainable on the cathode ray tube screen.

d. Replace that reference block with each of the other blocks in the set. Repeat steps b and c for each block and record the indications. Maintain water distance of 3 inches for each block.

e. Plot a curve of the recorded indications as shown in Figure 6.5(7). In the example shown, the near field (fresnel) zone extends from the 1/2-inch metal distance indication to the 2-inch metal distance indication. As the metal distance increases beyond 2 inches, the indications attenuate, or decrease, in height.
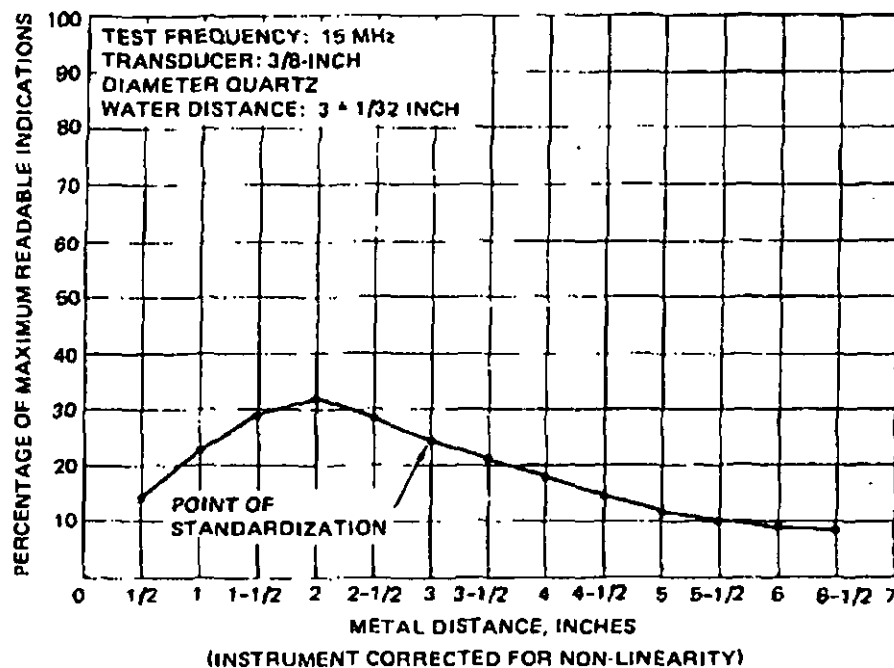

Figure 6.5(7). Typical distance/amplitude response curve.

Transducer Check

To improve accuracy during test equipment calibration, the characteristics of the transducer, as modified or distorted by the test instrument, are determined by recording a distance/amplitude curve from a 1/2-inch diameter steel ball immersed in water. A beam pattern, or plot, can also be obtained from the same steel ball at a fixed water-distance of 3 inches. It is well to remember that the curve and beam plot recorded in this procedure are not valid if the transducer is subsequently used with any test instrument other than the one used in this procedure. A complete analysis of transducer characteristics cannot be accomplished with the commercial ultrasonic testing equipment used in this procedure. To ensure maximum accuracy, the transducer may be calibrated with special equipment. In the procedure that follows, the apparatus used for checking the transducer is the same as that prescribed in the previous paragraphs for calibrating the instrument with reference blocks. The manipulator is set to allow a range in water distance of 0 to at least 6 inches from the face of the transducer to the ball surface.

a. Adjust the instrument gain control until the pip height is 50% of the maximum obtainable on the oscilloscope screen with the transducer positioned at a water distance of 3 ± 1/32 inch from the face of the transducer to the top surface of the ball. Exercise care in producing a true maximum indication by locating the transducer beam center on the center of the ball. Record this point of standardization.

b. After standardizing the instrument, set the water distance at 1/4 inch. Again, exercise care in using the manipulator to locate the transducer beam center on the center of the ball. Record the maximum indication. Do not readjust the instrument gain control in this or succeeding steps of the procedure.

c. Vary the water distance in 1/8-inch increments through a range of 1/4 to 6 inches. Record the maximum indication for each increment of water distance, using care each time the transducer is moved back that the beam center remains centered on the ball.

d. As shown in Figure 6.5(8), plot the recorded indications (corrected for any non-linearity) on a graph to demonstrate the axial distance/amplitude response of the transducer and particular test instrument used in the test.

e. Determine the transducer beam pattern by relocating the manipulator to obtain a 3 ± 1/32-inch water distance from the 1/2-inch diameter steel ball to the face of the transducer. While scanning laterally, 3/8-inch total travel, the height of the indication from the ball is observed while the transducer passes over the ball. Three distinct lobes or maximums are observed. The symmetry of the beam is checked by making four scans; displacing each scan by rotating the transducer in its mounting 45 degrees. The magnitude of the side lobes should not vary more than 10% about the entire perimeter of the ultrasonic beam. An acceptable transducer will produce a symmetrical beam profile which has side lobes with magnitudes no less than 20%, nor more than 30%, of the magnitude of the center lobe. The beam pattern or plot of an acceptable transducer is shown in Figure 6.5(9).
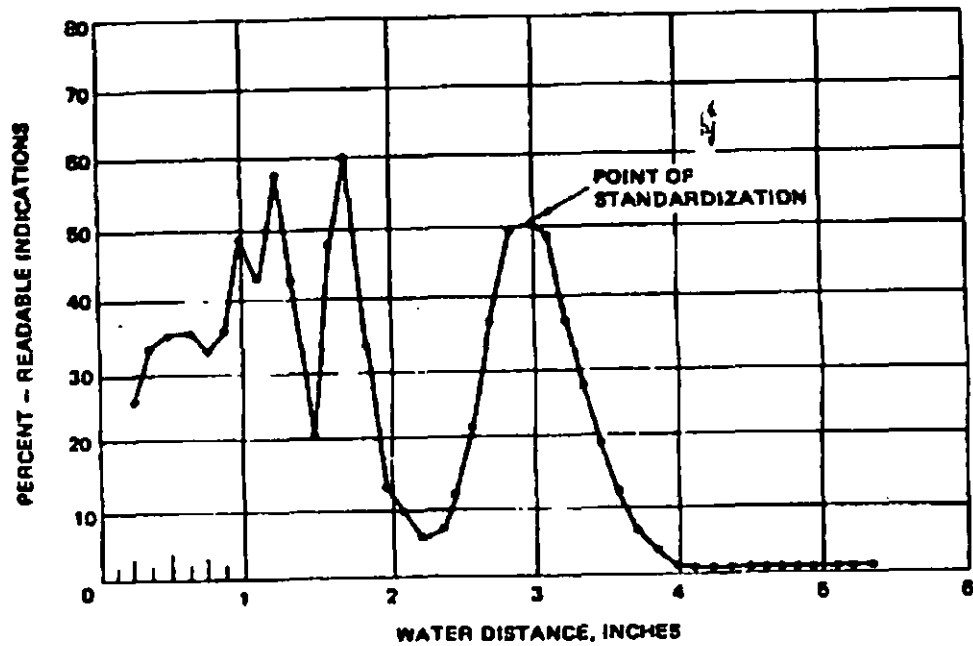
Figure 6.5(8). **Transducer axial distance/amplitude characteristics.**

QUARTZ IMMERSION TRANSDUCER —
3/8-INCH DIAMETER, WITH OPERA-
TIONAL FREQUENCY OF 15 MHz.

TARGET — 1/2-INCH DIAMETER STEEL
BALL AT A WATER DISTANCE OF
3 ± 1/32 INCH.

SIDE LOBE MAGNITUDE SHOULD BE
20% — 30% OF CENTER LOBE.

Figure 6.5(9). **Transducer beam pattern.**

6.6 APPLICATIONS

Ultrasonic examination is used in a wide range of applications. The principal one is the detection of internal flaws in most engineering metals and alloys. Bonds produced by welding, brazing, soldering and adhesive bonding can be ultrasonically inspected.

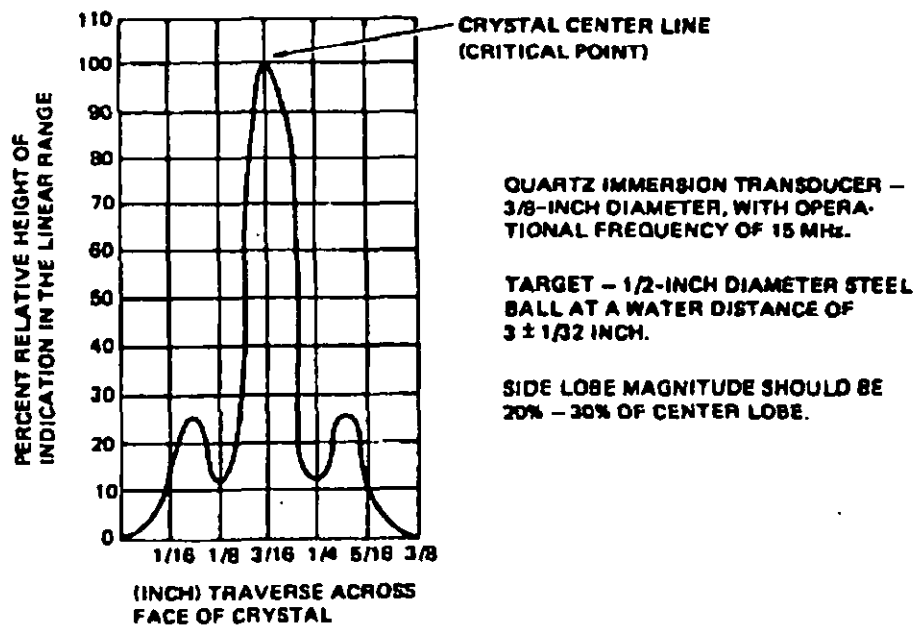The flaws to be detected include voids, cracks, inclusions, pipe, laminations, bursts and flakes. They may be inherent in the new material, may result from fabrication and heat treatment, or may occur in service from fatigue, corrosion or other causes.

Ultrasonics can also be used to measure thickness of metal sections. Structural material from a few thousandths of an inch to several feet in thickness can be measured to accuracies better than 1%.

Special ultrasonic techniques and equipment have been used on such diverse problems as the rate of growth of fatigue cracks, detection of bore hole eccentricity, measurement of elastic moduli, study of press fits, determination of nodularity in cast iron, and metallurgical research on phenomena such as structure, hardening, and inclusion count in various metals.

Ultrasonic examination can be used to detect both large and small discontinuities located either at the surface or deep within the part. The part can be made of a ferrous or nonferrous metal or of a nonmetal. Testing can be done by manual scanning or can be fully automated, with either visual interpretation or permanent recording of results. Ultrasonic examination can be performed on either flat or curved surfaces, and can be performed when only one surface of a part is accessible, even when the area to be inspected is remote from the accessible surface.

The only limitations in its applications for materials are usually foams, where high porosity exists, or for materials where high damping exists (certain corks, rubbers, etc.). Geometric limitations exist in terms of part designs, orientations, surface finishes, etc.

THIS PAGE INTENTIONALLY LEFT BLANK

6.7 SPECIFIC GUIDELINES

Ultrasonic testing, as all NDT methods, requires wise applications with full knowledge of the limitations involved. The following guidelines can be of value only as they can be intelligently applied to each individual problem.

6.7.1   GUIDELINE FOR DESIGNERS

Designers should know the following: choosing the proper specifications for NDT is important, but most specifications such as MIL-I-6870 and MIL-STD-2154 are general and do not provide the details required to actually perform an inspection. Some designers believe that with the choice of a specification, everything else is automatic. Close communications must be established with QA and materials and testing engineers to ensure that the details and decisions required after a general specification is chosen will accomplish the original intent of the design. In ultrasonics, the cost of calibrating and standardizing normally increases as the limit in the size of flaws to be detected decreases. If the minimum defect size approaches the inspection beam size, and especially if it approaches wavelength size, extensive correlations may be required before the ultrasonic testing can be effective. Therefore, when tight specifications are required, the design engineer must become aware of these costs and give guidance to possible trade-offs. Ideally, changes in design that reduce inspection costs should be made early. This cannot occur unless the designer has personally taken the interest necessary to understand these choices.

The designer should read section 6.4.4 on reference standards and section 6.4.5 on interpretations of indications where it is pointed out that standards and calibrations are valid only to the degree that the standards match the alloy, shape, and acoustic property of the specimen. When designers are able to place one or more artificial reflectors in their design to represent critical flaw sizes, then the NDT inspection has a standard that is exactly the same alloy, shape, and acoustic property, since it is the part itself that is being used. This approach saves much calibration time and increases the reliability of the inspection. Designers, if they consider these possibilities early in the design phase, can often accomplish this at far less cost than that required to inspect without them.

6.7.2   GUIDELINE FOR PRODUCTION ENGINEERS

Ultrasonic inspection is extensively used by production engineers, to inspect raw materials before they are processed, to inspect parts during their fabrication, and to actually control some of their machine operations. Coordinations of the inspections of the parts during their fabrications are usually made with QA. In some large operations, all materials are originally brought and inspected at a standard quality level. Then portions of that material may later be needed where a higher quality level may be required. Reinspection is then performed to "upgrade" the material for this new use. This effort of inspecting quality "into" a part is rarely successful and should be brought to a designer's attention when this occurs.

6.7.3   GUIDELINES FOR QA PERSONNEL

Ultrasonics, especially where C-scans are produced with a direct "black and white" readout, can often be assumed to be real. That is, images seen on the scan (indications) are often assumed to be the images of the flaws or of variables in the material. The images formed by ultrasonics, especially for small dimensional shapes, are very non-linear and thus indication images cannot be used as flaw images except through proper calibration and the interpretations that it can provide.

Many times, QA must work with both NDT research engineers and NDT production engineers. They need to understand that basic differences can exist between these disciplines. The production engineers are paid to run efficient inspections, and this requires maximum inspection rates that just barely allow detection of the smallest unacceptable flaws. This approach and orientation rarely provide maximum inspection information. At the same time, one in a research environment, trained to maximize the inspection information, should not routinely be used by QA to determine acceptable production rates. A need often exists for input from both, and a clear understanding of their differences in background should be recognized and appreciated.

6.7.4   GUIDELINES FOR NDT ENGINEERS

In ultrasonics, the NDT Engineer has a duty to explain and instruct those interested in the results, of the limitations and interpretations of the results. Where a pulse-echo method is employed, as an example, the equipment sends out a wave pulse and listens for an echo. When an echo is received, the machine does not know why an echo is received. The machine cannot know what caused the echo to be returned. Only the operator, with his knowledge of the situation, his knowledge of the part being inspected, and his ability to weigh various possibilities, is in a position to make an immediate interpretation. Because of multiple reflections, standing waves, interference patterns, near-field effects, and a multitude of non-linear interactions that can occur in ultrasonics, proper interpretations are critical. The NDT Engineer has the greatest responsibility in seeing that these interpretations are correct and are properly used.

6.7.5   GUIDELINES FOR NDT TECHNICIANS

Technicians must stay alert to changes in their equipment. In ultrasonics, the equipment is complicated, both electronically and mechanically. The final results are based upon a series of interdependent operations, and therefore the results are almost always being affected in some small degree first in one direction and then another. Transducers can age. What was a good transducer yesterday may not be a good one today. Noting small differences is often important. In ultrasonics, where immersion test methods are conducted, the presence of air bubbles will be one of the biggest problems. There is much air in water (that is why fish can live in water) and the amount of air in the water depends upon its temperature. Air bubbles can appear even though care is used to originally place a part in water without any air bubbles attached.

Air bubbles can actually grow, collecting air from the water itself. This especially occurs if fresh water has just come from a cold, high pressure source, or the part is warmer than the water, or the average temperature of the water is increasing. These problems also depend upon the interfacial energy relationship between the water and the material and whether there are "nucleation" sites upon which the bubbles can grow. Therefore, some parts may never have these problems, and others will always have these problems. They are common enough, though, that they should always be watched for and care exercised that they do not produce false indications. Properly designed standards will reveal many of the ultrasonic test problems that can occur during production inspection.

THIS PAGE INTENTIONALLY LEFT BLANK

6.8 SAFETY

Standard laboratory safety procedures for the handling of electrical equipment
are applicable to almost all ultrasonic systems. The transducers are often in
circuits that use 300 to 1000 volts. Proper grounding and insulation should
always be employed. Where automatic scanning devices are employed, great care
must be exercised to protect personnel from moving belts or drives and of
being caught between moving parts. There should also be safety switches and
position limit switches to ensure that moving machinery does not go beyond
certain safe limits. In large operations or the inspection of large parts,
safety in the handling of the inspected parts cannot be overlooked. Many
times large hoists or cranes are involved, and methods of placing and
adjusting heavy parts must be checked and approved. Large amounts of water,
and various additives, are sometimes involved in ultrasonic testing. The
unexpected release of these liquids, due to a rupture of the water tank (by
accident or otherwise), might be a safety consideration. A fungicide shall be
added to an immersion bath to protect the health of the operator.

THIS PAGE INTENTIONALLY LEFT BLANK

MIL-HDBK-728/6

MIL-HDBK-728/6

6.9 GLOSSARY

AMPLITUDE The vertical pulse height of a received ultrasonic signal, usually base to peak, when indicated by an A-scan presentation.

ANGLE BEAM A wave train introduced into a test object so that the ultrasonic beam axis centerline is at an angle, other than 0 degrees, to the normal to the entry plane of the test object.

ANGLE OF INCIDENCE The angle that the axis of an ultrasonic beam makes with the normal to a surface at the point of incidence.

ANGLE OF REFLECTION The angle that the axis of a reflected ultrasonic beam makes with the normal to a reflecting surface at the point of incidence.

ANGLE OF REFRACTION The angle between the axis of a refracted beam and the line normal to the boundary between two media with different speed of sound.

AREA-AMPLITUDE RESPONSE CURVE A curve showing the changes in the amplitude of ultrasonic response to reflectors of different areas located at equal distances from the search unit in an ultrasonic-conducting medium.

A-SCAN A method of data presentation utilizing a horizontal base line that indicates distance, or time, and a vertical deflection from the base line which indicates ultrasonic amplitude.

ATTENUATION The loss of ultrasonic energy within a medium due to scattering and absorption.

ATTENUATION COEFFICIENT Factor that describes the decrease in ultrasound amplitude with distance in a given medium. Normally expressed in decibels per unit length.

ATTENUATOR A device for altering the amplitude of an ultrasonic signal in known increments, usually decibels.

BACK REFLECTION Indication of the ultrasonic echo from the far boundary of the material under test.

BASELINE The distance/time axis in an A-scan display.

BEAM AXIS The acoustic centerline of an ultrasonic search unit's beam pattern as described by the locus of points of maximum sound pressure in the far field, and its extension into the near field.

BEAM SPREAD A divergence of the ultrasonic wave train as it travels through a medium.

BOTTOM ECHO See Back Reflection.

B-SCAN PRESENTATION A method of data presentation in which the travel time of an ultrasonic pulse is represented as a displacement along one axis, and probe movement (generally rectilinear) is represented as a displacement along the other axis. In the display, reflected pulses are shown in contrast to the background.

BUBBLER A device using a liquid stream to couple an ultrasonic beam to the test piece.

COMPRESSIONAL WAVE See Longitudinal Wave.

CONTACT TESTING A method of testing in which the transducer contacts the test surface, usually through a thin layer of complaint.

CORNER EFFECT The reflection of a sound beam in a direction parallel to an incident beam directed normal to the intersection of two perpendicular planes.

COUPLANT A substance used between the search unit and test surface to permit or improve transmission of ultrasonic energy.

CRITICAL ANGLE The incident angle of the sound beam beyond which a specific refracted or reflected mode of vibration no longer exists.

CRYSTAL See Element, Piezoelectric.

C-SCAN A method of data presentation yielding a plan view of the test object and the discontinuities therein.

DAMPING Limiting the duration of vibration in an ultrasonic search unit by either electrical or mechanical means.

DEAD ZONE Corresponds to the distance in the material from the surface of the test object to the nearest inspectable depth. It is determined by the characteristics of the material, ultrasonic test instrument and search unit.

DECIBEL (dB) Twenty times the logarithmic expression of the ratio of two amplitudes. $dB = 20 \log_{10}$ (amplitude ratio).

DEFECT A discontinuity or group of disconinuities which produce indications that do not meet a specified acceptance criteria.

DELAYED SWEEP A horizontal sweep whose start is delayed in order to prevent the appearance of unwanted early response information on the screen.

DGS-DISTANCE GAIN SIZE Distance amplitude curves permitting prediction of reflector size compared to the response from a back surface reflection.

DISCONTINUITY A detectable interruption in the material which may or may not have undesirable connotations.

DISTANCE AMPLITUDE CORRECTION (DAC) (Swept Gain, Time corrected gain, time variable gain, etc.) Electronic charge of amplification to provide equal amplitude from equal reflectors at different distances.

DISTANCE-AMPLITUDE CURVE A curve relating ultrasonic echo amplitudes from equal reflectors at different distances in the material.

DIVERGENCE See Beam Spread.

DUAL SEARCH UNIT (TWIN PROBE) A search unit containing two elements, one a transmitter, the other a receiver.

DYNAMIC RANGE The ratio of maximum to minimum reflective areas that can be distinguished on the display at a constant gain setting.

ECHO Indication of reflected energy.

ELEMENT, PIEZOELECTRIC Portion of a single crystal or polycrystalline sintered ceramic having piezoelectric properties, used for the generation and/or detection of ultrasonic energy.

EQUIVALENT FLAT BOTTOM HOLE The flat bottomed hole reflector in a similar material and geometry with a diameter that produces the same ultrasonic echo amplitude as the reflector under evaluation.

FALSE INDICATION In nondestructive inspection, an indication that may be interpreted erroneously as a discontinuity or defect; a non-relevant indication, e.g., artifacts.

FAR FIELD The zone of the ultrasonic beam of a non-focused search unit that extends beyond approximately $D^2/4\lambda$ (where D is the diameter of the transducer and λ is the wavelength). In this zone the amplitude of the ultrasonic waves decrease steadily with distance.

FLAW An irregularity in the material which is generally undesirable, but may or may not be severe enough to immediately render the part unfit for intended use.

FOCUSED BEAM Converging energy of the sound beam at a specified distance.

FREQUENCY (ACOUSTIC) The number of oscillations per second experienced by a particle or point in a medium caused by the passage of an acoustic wave through it.

FREQUENCY (CENTER) See Frequency (Dominant).

FREQUENCY (DOMINANT) That frequency at which the overall response of an ultrasonic pulse-echo flaw detection system is a maximum. NOTE: the 'system' includes the pulser, the transducer as a transmitting element, the pulse propagation path, the transducer as a receiving element, and electronic instrumentation associated with receiving, amplifying and displaying a received signal.

FREQUENCY (EXAMINATION) The nominal frequency at which the examination is performed.

FREQUENCY (FUNDAMENTAL RESONANCE) The lowest acoustic frequency which will cause a condition of resonance to be established in a given material of given thickness. NOTE: This frequency will be such that the wavelength in the given material is equal to twice the given thickness.

FREQUENCY (PULSE REPETITION) The number of times per second an electroacoustic transducer is excited to produce a pulse of acoustic energy.

FRESNEL FIELD (FRESNEL ZONE) See Near Field.

GATE A selected transit time range from which signals may be monitored or extracted for further processing.

GATE THRESHOLD An adjustable level such that while any echo within the gate exceeds the set level, an on/off signal (e.g., to a light or a recording pen) is activated.

GHOST ECHO See Wrap Around.

GRASS See Hash.

GRAZING INCIDENCE Immersion inspection with the beam directed at a glancing angle to the test surface.

HASH Numerous small indications along the baseline of the display indicative of background noise sometimes caused by many small inhomogeneities in the material.

HOLOGRAPHY (ACOUSTIC) An inspection system using the phase interference between ultrasonic waves from an object and a reference signal to obtain an image of reflectors in the object under test.

IMMERSION TESTING An examination method where the transducer and the material are submerged at least locally in a fluid, usually water.

IMPEDANCE (ACOUSTIC) The product of density and sound velocity. The property which determines acoustic transmission/reflection characteristics at a boundary between two media.

INDICATION In nondestructive evaluation, evidence of a discontinuity that requires interpretation to determine its significance.

INITIAL PULSE (MAIN BANG) Response of the ultrasonic system display to the transmitted pulse.

INTERFACE The boundary between two materials.

IRRELEVANT INDICATION An indication resulting from something other than a discontinuity of interest.

LAMB WAVE A type of wave that propagates within the thickness of a plate, and that can only be generated at particular values of angle of incidence, frequency, and plate thickness. The velocity of the wave is dependent on the mode of propagation and the product of plate thickness and frequency.

LINEARITY (AMPLITUDE) The characteristic of an ultrasonic testing system indicating its ability to display amplitudes proportional to amplitudes of ultrasonic waves coming back from a reflector.

LINEARITY (DISTANCE) The characteristic of an ultrasonic testing system indicating its ability to display signals at spacings proportional to the sound path distance between corresponding reflectors.

LONGITUDINAL WAVE Those waves in which the particle motion of the material is in the same direction as the wave propagation.

LOSS OF BACK REFLECTION Absence of or a significant reduction of an ultrasonic indication from the back surface of the article being inspected.

MATERIAL ENVELOPE The portion of material at the surface of a test piece which will later be removed to produce the finished part.

MODE The manner in which acoustic energy is propagated through a material as characterized by the particle motion of the ultrasonic wave.

MODE CONVERSION The process by which a wave of a given mode of propagation generates waves of other modes of propagation by reflection or refraction.

MULTIPLE BACK REFLECTIONS Successive echoes from the far boundary of the material being examined.

NEAR FIELD The zone directly in front of an ultrasonic transducer extending to a distance of approximately $D^2/4\lambda$ (where D is the diameter of the transducer and λ is the wavelength). In this zone components of the ultrasonic wave from different portions of the transducer interfere to produce pressure maxima and minima.

NOISE Unwanted disturbances from equipment or the material under test superposed upon the received ultrasonic signal.

NORMAL INCIDENCE Condition in which the transducer beam is perpendicular to the test surface.

PAINTBRUSH TRANSDUCER A rectanglar transducer usually constructed with a number of piezoelectric elements which has a wide beam to sweep out large areas.

PENETRATION The maximum depth in a material from which useful ultrasonic back reflections could be obtained.

PIEZOELECTRIC EFFECT The characteristic of certain materials to generate electrical charges when subjected to mechanical vibrations, and conversely to generate mechanical vibrations when subjected to electrical pulses.

PLATE WAVE   See Lamb Wave.

PROBE   See Transducer or search unit.

PULSE   A short wave train.

PULSE ECHO METHOD   An ultrasonic inspection method in which the presence and position of a reflector are indicated by the reflected pulse amplitude and time.

PULSE LENGTH   A measure of the duration of a wave train, expressed in time or number of cycles.

PULSE RATE   See Frequency

RF (RADIO FREQUENCY) DISPLAY   A display showing unrectified ultrasonic signals.

RANGE   The ultrasonic path length that is displayed.

RAYLEIGH WAVE   An ultrasonic surface wave in which the particle motion is elliptical and the effective penetration is approximately a wave length. The waves follow the curvature of the part and reflections occur only at sudden changes in the surface.

REFERENCE BLOCK   A specimen with geometry and material designed to produce ultrasonic reflections of known characteristics for purposes of comparison.

REFLECTION   See Echo.

REFLECTOR   An interface at which a ultrasonic beam encounters a change in acoustic impedance, and reflects at least part of the energy.

REFRACTION   The change in direction of the ultrasonic beam as it passes obliquely from one medium to another, with a different sound wave velocity.

REJECT (SUPPRESSION)   A electronic control which minimizes or eliminates low amplitude signals (or noise) but may cause display non-linearity.

RESOLUTION   The ability of ultrasonic equipment to give simultaneous, separate indications from discontinuities having nearly the same range and/or lateral position with respect to the beam axis.

RESONANCE METHOD   A technique in which continuous ultrasonic waves are varied in frequency to discriminate some property of the part, such as thickness stiffness, or bond integrity.

SATURATION   Condition observed on the display resulting from a signal of such a magnitude that an increase in the signal produces no observable increase in the display amplitude.

SCANNING   Relative movement of the transducer and the test piece in order to interrogate a volume of material.

SCATTERING The perturbation of a ultrasonic beam by small reflectors in the propagation path.

SCANNING INDEX The distance the transducer is moved perpendicular to the traverse direction after one transverse of the part.

SE PROBE See Dual Search Unit.

SEARCH UNIT OR TRANSDUCER An electro-acoustic device used to transmit and/or receive ultrasonic energy in order to interrogate a specimen. The device frequently consists of piezoelectric element(s), backing material, case, connector and a front protective covering or lens or wedge.
SENSITIVITY A measure of the ability of an ultrasonic system to detect small discontinuities.

SHEAR WAVE Wave motion in which the particle motion is perpendicular to the direction of ultrasonic propagation.

SHEAR WAVE TRANSDUCER (Y CUT QUARTZ SEARCH UNIT) A transducer used for generating and detecting normal incidence shear waves.

SIGNAL-TO-NOISE RATIO The ratio of the amplitude of an ultrasonic indication to the amplitude of the background noise.

SKIP DISTANCE In angle beam testing, the distance along the test surface from the sound entry point to the point at which the sound returns to the same surface, having been reflected from the far surface of the test object.

STRAIGHT BEAM See Normal Incidence.

SURFACE WAVE See Rayleigh Wave.

SWEPT GAIN See DAC.

THROUGH TRANSMISSION METHOD A method in which reflectors in an object are detected by monitoring the ultrasonic energy incident on a receiving transducer after the energy has propagated through the object from a transmitting transducer.

TRANSDUCER OR SEARCH UNIT An electro-acoustic device used to transmit and/or receive ultrasonic energy in order to interrogate a specimen. The device frequently consists of piezoelectric element(s), backing material, case, connector and a front protective covering or lens or wedge.

TRANSFER MECHANISM A procedure to account for differences in ultrasonic response due to differences in surface texture, curvature, attenuation, etc., between a reference block and the test object.

TRANSVERSE WAVE See Shear Wave.

ULTRASONIC Pertaining to mechanical vibrations having a frequency greater than approximately 20,000 Hz.

ULTRASONIC SPECTROSCOPY Analysis of the frequency content of an ultrasonic wave.

VEE PATH The angle-beam path in material starting at the transducer examination surface, through the material to the back surface, continuing to the examination surface in front of the search unit, and reflection back along the same path to the transducer if a discontinuity is encountered. The path is usually shaped like the letter "V".

VERTICAL LIMIT The maximum readable level of vertical indications determined either by an electrical or a physical limit of an A-scan presentation.

VIDEO PRESENTATION Display of the rectified and usually filtered rf ultrasonic signal.

WATER PATH (WATER TRAVEL) The distance from the transducer to the test surface in immersion or water column testing.

WAVE FRONT A continuous surface drawn through the most forward points in a wave disturbance which have the same phase.

WAVE INTERFERENCE A series of pressure minima and maxima resulting from the superpositon of waves.

6.10 BIBLIOGRAPHY

1. Classroom Training Handbook, CT-6-4, "Nondestructive Testing, Ultrasonic," (General Dynamics Convair, San Diego) 1981 (Second Edition.)

2. NASA SP-5113, "Nondestructive Testing, A Survey," (U.S. Government Printing Office, Washington D.C.) 1973.

3. Ultrasonic Testing of Materials, J&H Krautkramer, (Springer-Verlag, Berlin) 1977.

4. Metals Handbook, Vol. 11, "Nondestructive Inspection and Quality Control," (American Society for Metals, Metals Park, OH.) 1976 (8th Edition).

5. Nondestructive Testing, W.J. McGonnagle, (McGraw-Hill Book Co., N.Y.) 1961.

6. Basic Physics In Diagnostic Ultrasound, J.L. Rose and B.B. Goldberg, (John Wiley and Sons, N.Y.) 1979.

7. Nondestructive Testing Handbook, R.C. McMaster, (Ronald Press Co., N.Y.) 1959.

THIS PAGE INTENTIONALLY LEFT BLANK

6.11 INDEX

Custodians: Preparing activity:

   Army -- MR   Army -- MR
   Navy -- AS
   Air Force -- 20   Project No. NDTI-0047

Review activities:

   Army -- AR
   Navy -- OS

(WP ID # 1343P DISK 0282A. FOR AMMRC USE ONLY.)

6.11-3

THIS PAGE INTENTIONALLY LEFT BLANK

☆U.S. GOVERNMENT PRINTING OFFICE: 1987-704-036/70675

INSTRUCTIONS: In a continuing effort to make our standardization documents better, the DoD provides this form for use in submitting comments and suggestions for improvement. All users of military standardization documents are invited to provide suggestions. This form may be detached, folded along the lines indicated, taped along the loose edge (DO NOT STAPLE), and mailed. In block 5, be as specific as possible about particular problem areas such as wording which required interpretation, was too rigid, restrictive, loose, ambiguous, or was incompatible, and give proposed wording changes which would alleviate the problems. Enter in block 6 any remarks not related to a specific paragraph of the document. If block 7 is filled out, an acknowledgement will be mailed to you within 30 days to let you know that your comments were received and are being considered.

NOTE: This form may not be used to request copies of documents, nor to request waivers, deviations, or clarification of specification requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

(Fold along this line)

(Fold along this line)

DEPARTMENT OF THE ARMY

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

BUSINESS REPLY MAIL

FIRST CLASS   PERMIT NO. 12062   WASHINGTON D. C.

POSTAGE WILL BE PAID BY THE DEPARTMENT OF THE ARMY

Director
U. S. Army Materials Technology
 Laboratory
ATTN: SLCMT-MSR-ES
Watertown, MA 02172-0001

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL
(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
MIL-HDBK-728/6	

3a. NAME OF SUBMITTING ORGANIZATION

4. TYPE OF ORGANIZATION *(Mark one)*

☐ VENDOR

☐ USER

☐ MANUFACTURER

☐ OTHER *(Specify):* _____

b. ADDRESS *(Street, City, State, ZIP Code)*

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional	8. DATE OF SUBMISSION *(YYMMDD)*

DD FORM 1426

PREVIOUS EDITION IS OBSOLETE.