Nondestructive Examination (NDE) Technology and Codes
Student Manual

Volume 2

Chapter 8.0

Introduction to Ultrasonic Examination

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8.0 INTRODUCTION TO ULTRASONIC EXAMINATION

Learning Objectives:

To enable the student to:

1. Understand the basic principles of the generation, transmission, and reflection of ultra-sound.

2. Know the personnel qualification and certification requirements.

3. Become familiar with the various techniques used in ultrasonic examination (UT).

4. Understand the steps involved with calibration.

5. Become familiar with the variables affecting UT.

6. Understand the common interpretation and code requirements.

7. Identify the advantages and limitation of UT.

8.1 History

Practical use of ultrasound for NDE began in the 1920's. Sokolov was a major pioneer, using the through-transmission technique whereby sound is transmitted through the material, to a receiver. Reduction in the received signal amplitude indicated the possibility of discontinuities in the path of the sound beam.

Development of more advanced equipment in the 1940's expanded the use of pulse-echo ultrasound, which derives information from the sound making round trips, and required access to only one side of the material. Another technique, resonance testing, depends on the resonant frequency of the material being examined.

8.2 Personnel Qualification and Certification

Of all the NDE methods, UT is the most subjective and therefore depends greatly on the qualifications and expertise of the examiner.

8.2.1 ASME Section V

The 2007 Edition with 2008 Addenda of the ASME Code Section V requires that NDE personnel be qualified in accordance with either:

SNT-TC-1A (2006 Edition), or
ANSI/ASNT CP-189 (2006 Edition)
ACCP

Qualification in accordance with a prior edition of either SNT-TC-1A or CP-189 is considered valid until recertification. Recertification must be in accordance with SNT-TC-1A (2006 Edition), CP-189 (2006 Edition) or ACCP .

A Level II Ultrasonic Examiner, who is a high school graduate, must complete one of following for Section V and only the CP-189 requirements for Section XI.

The SNT-TC-1A requirements are:

	Training	Experience
Level I	40 hours	210* hrs /400**hrs
Level II	40 hours	630* hrs /1200 **hrs

NOTES:

1. To certify to Level II directly with no time at Level I, the training and experience for Level I and II shall be combined.
2. Training hours may be reduced with additional engineering or science study beyond high school. Refer to Chapter 2 and SNT-TC-1A.
3. There are no additional training requirements for Level III. Refer to Chapter 2 of this manual for Level III requirements.

The CP-189 requirements are:

	Training	Experience
Level I	40 hours	200*/400**
Level II	40 hours	600*/1200**

*Hours in UT/** Total Hours in NDE

NOTES:

1. Experience is based on the actual hours worked in the specific method.
2. A person may be qualified directly to NDT Level II with no time as certified Level I providing the required training and experience consists of the sum of the hours required for NDT Levels I and II.
3. The required minimum experience must be documented by method and by hour with supervisor or NDT Level III approval.
4. While fulfilling total NDT experience requirement, experience may be gained in more than one (1) method. Minimum experience hours must be met for each method.

8.2.2 ASME Section XI

Ultrasonic examination is the most widely used method for the detection and evaluation of piping systems' flaws during In-service Inspection (ISI) of nuclear power plants. However, due to the complexity of the method and the factors affecting the examination, such as pipe geometry and material type, the training and qualification of examiners have been problematic and under constant evaluation since the early 1980's.

During the mid-seventies, boiling water reactors (BWRs) were found to contain extensive intergranular stress corrosion cracking (IGSCC) in certain stainless steel piping. The NRC called for increased examinations and for plant owners to improve the effectiveness of ultrasonic examinations. The Electric Power Research Institute (EPRI), NRC, and plant owners conducted a number of studies on the effectiveness of ISI ultrasonic examiners and their ability to detect IGSCC. The results showed qualified examiners were missing critical discontinuities. The industry instituted special training and certification examinations given through EPRI to better qualify examiners to find IGSCC. It is critical to remem-

ber that the requirements of CP-189 (1995 Editions) are minimum for Section XI. The specific and practical examinations must be directed at the specific techniques an examiner will use in the field. To have examiners spend 80 percent of their time doing erosion/corrosion (straight beam) examinations and then administer a simple angle beam practical examination is not adequate for the performance of ISI weld examinations.

Section XI requires that personnel performing NDE be qualified and certified using a written practice prepared in accordance with ANSI/ASNT CP-189 as amended by Section XI. IWA 2314 states that the possession of an ASNT Level III Certificate, which is required by CP-189, is not required by Section XI. Section XI also states that certifications to SNT-TC-1A or earlier editions of CP-189 will remain valid until recertification at which time CP-189 (1995 Edition) must be met.

To assure that an examiner performing ISI ultrasonic examinations is properly qualified, ASME Section XI has added extensive requirements above the minimums as outlined in CP-189. Specifically, Appendix VII was added to Section XI. The following section outlines basic requirements for ASME Section XI. (Refer to ASME Section XI, Appendix VII for detailed information.)

The 2007 edition with 2008 addenda of Section XI, requires certification to CP-189 - 1995 as modified in ASME Section XI Mandatory Appendix VII article VII 4000.

The requirements of Appendix VII are:

	Classroom	**Laboratory**	**Experience**
Level I	40	40	250 hours
Level II	40	40	800 hours
Level III	40	-	Options -see below

Option I - Graduate of a 4 year accredited engineering or science college or university with a degree in engineering or science, plus 2 years experience in NDE in an assignment comparable to that of an NDE Level II in the ultrasonic examination method. At least 1 year of this experience shall be in nuclear applications and shall include the actual performance of examinations and evaluation of examination results. Also, it requires 4,200 hours of total experience with 2,100 hours in nuclear applications.

Option 2 - Completion with a passing grade of at least the equivalent of 2 full years of engineering or science study at a university, college, or technical school, plus 3 years experience in an assignment comparable to that of a Level II in the ultrasonic examination method. At least 2 years of this experience shall be in nuclear applications and shall include the actual performance of examinations and evaluation of examination results. Also, it requires 6,300 hours of experience with 4,200 hours in nuclear applications.

Option 3 - High school graduate, or equivalent, plus 4 years experience in an assignment comparable to that of a Level II in the ultrasonic examination method. Also, it requires 8,400 hours of experience with 4,200 hours in nuclear applications.

Appendix VII also addresses NDE Instructor Qualification, Annual Training (minimum of 10 hours per year), Examinations (with much emphasis on performance demonstration), and Qualification Records.

Appendix VII Supplement 1 contains the minimum content for initial training courses.

8.3 Principles

Sound is the transmission of mechanical energy, in the form of vibrations, through a material. Although sound can be propagated in all three states of matter; solids, liquids, and gases, factors such as type of sound wave, material composition, and wavelength can make propagation difficult or impossible in a given situation.

8.3.1 Frequency

Frequency is the rate of vibration or the number of vibrations per second. Because sound waves are in motion, frequency can also be viewed as the number of complete waves which pass a given point during 1 second. One complete unit of vibration is called a cycle. A cycle is graphically represented by a sine curve and consists of two opposing motions, such as forward and backward, or up and down. The rate of vibration, or cycles per second, is expressed in "hertz" units as follows:

- Hertz (Hz) = cycles per second,
- Kilohertz (KHz) = one thousand cycles per second, and
- Megahertz (MHz) = one million cycles per second.

The audible range, which is the range of human hearing, is 20 Hz to 20 KHz. Ultrasound encompasses all frequencies higher than 20 KHz. UT utilizes only a portion of the ultrasonic range. Most commercial UT is performed within the range of 100 KHz to 25 MHz; a few applications are performed both above and below this frequency band. Actual examination frequency depends on the frequency of the transducer selected.

8.3.2 Velocity

Velocity is the speed at which sound travels. It is expressed as distance traveled per unit time. The most common units of time in UT are the second and microsecond (µsec). A microsecond is one millionth of a second.

The velocity of sound depends upon:

- Density and elasticity of the material through which sound is traveling,
- Wave mode (the manner in which material particles vibrate as sound travels through the material), and
- Material temperature, which has a minor effect on sound velocity for temperatures greater than 150°F.

Several formulas used in UT employ material velocity as a variable. The most convenient unit for calculating these formulas is kilometers per second (km/sec), although inches per second and centimeters per microsecond are sometimes encountered.

8.3.3 Wavelength

A vibration in motion is often called a sound wave. A series of sound waves sent into an object is often called a pulse.

Wavelength is an important variable in UT and is defined as the distance from one point on an ultrasonic wave train to the next identical point (e.g., from trough to trough or peak to peak) (Figure 8-1).

It is also defined as the distance sound travels within the duration of one complete cycle.

Wavelength (represented by λ, the Greek letter lambda) is calculated by dividing velocity (V) by frequency (f), as follows:

λ (mm) = V (km/sec)/f (MHz) . (8-1)

8.3.4 Transmission/Reflection

Sound reflects when it strikes a surface called an acoustic interface. An echo is therefore defined as a reflection from an acoustic interface. An acoustic interface is the boundary between two materials with different acoustic impedances. Acoustic impedance is defined as the opposition a material offers to the passage of sound. It is the product of the material's velocity and density. As the impedance ratio increases between the interfaces of two materials the greater the sound reflection at this interface boundary and hence less sound is transmitted into the second material. The percentage of sound reflected from an interface, where Z_1 is the acoustic impedance of the medium through which the sound is initially traveling, and Z_2 is the acoustic impedance of the medium that the sound meets at the interface and is reflected, is calculated as follows:

(8-2)

$$\% \text{ Sound reflected} = (Z_1-Z_2)^2/(Z_1+Z_2)^2 \times 100$$

Material discontinuities reflect sound because they have an acoustic impedance different from the material being examined (Figure 8-2). In addition to acoustic impedance, a number of other factors reduce the amplitude of the echo that the transducer receives from a discontinuity. The size, shape, and orientation of the reflector all affect its echo response. Position of a reflector is particularly important due to the effects of sound beam geometry and material properties. The more the sound beam has spread at the point of reflector interception, the less will be the reflected sound pressure per unit area. In addition, as sound travels through test material, increased scattering and absorption of the sound by the material's own structure is experienced. When examining thick sections, some type of distance/amplitude correction (DAC) must be considered to compensate for amplitude losses caused by the sound beam and test material.

8.3.5 Attenuation

Sound amplitude decreases (as it propagates in the material) are called sound attenuation. Attenuation is due to several factors:

Absorption - Sound is absorbed by the braking effect on the particle motion. Lost energy is converted to heat.

Scatter - Grain boundaries of the material cause the sound to scatter.

The amount of sound attenuation within a material is governed by the density, elasticity, grain size, and grain structure of the material. These factors are affected by alloying, heat treatment, working, etc.

8.3.6 Instrumentation and Control

Figure 8-3 shows a block diagram of a typical ultrasonic flaw detection instrument. The pulse generator (trigger, clock) transmits an electrical pulse simultaneously to the transducer (search unit) and the time base of the cathode ray tube (CRT). The transducer converts the electrical pulse into sound which is transmitted into the material. The time base (sweep generator) generates the X sweep across the CRT. When the sound pulse is reflected back to the transducer, it is converted back into an electrical pulse and is amplified before being fed to the Y axis of the CRT. This pulse deflects the time base vertically and produces a peak.

8.3.7 Ultrasonic Wave Propagation

Sound waves travel through materials by displacing tiny particles of the material, generally at the molecular level. Depending on the manner in which vibrations are introduced, the particle displacements exhibit certain behaviors, called wave modes, as the vibrations travel.

There are two basic wave modes, which differ from each other depending on how material particles move relative to the direction of transmitted energy. Longitudinal waves (also known as compressional waves) are characterized by the particle motion being parallel to the direction of wave travel (Figure 8-4). Transverse waves (also known as shear waves), are defined by particle motion perpendicular to wave travel (Figure 8-5). The difference in wave motion causes these wave modes to also differ from each other in their relative velocity as well as in their ability to propagate in the various states of matter.

Ultrasonic energy propagates through materials in several different ways depending upon the manner in which the particles within the carrying medium move relative to the direction of wave propagation.

There are four forms of wave propagation through materials:

- Compression (or longitudinal),
- Shear (or transverse),
- Surface (or Rayleigh), and
- Plate (or Lamb).

Compression - The term “compression” is used to describe the wave propagation where the particle motion is parallel to the direction of propagation. The particles compress together, then rarify (Figure 8-4). This motion passes the sound energy along the material in the form of a wave. In this case there is a change in volume of the material, as particle motion takes place, within the elastic limit.

Compression or longitudinal waves are characterized by alternating zones of compression (high particle density) and rarefaction (low particle density) (Figure 8-4). Longitudinal waves develop particle motion in solids, liquids, and gases, and their acoustic velocity is higher in any given material than other types of waves as is their wavelength for a given frequency.

The velocity of compressional waves depends on the density and elasticity of the material.

Shear - The term “shear” is used to indicate that the particle motion is at right angles to the direction of propagation. In this case distortion is caused by particle movement, with no change in volume. Figure 8-5 illustrates the shear wave particle motion. Shear waves have a velocity approximately one-half that of compression waves and a shorter wavelength than compression waves.

Shear or transverse waves are characterized by alternating zones of peaks (upward particle displacement) and troughs (downward particle displacement) (Figure 8-5). Transverse waves require rigidity and can travel in solids only, and their acoustic velocity is approximately half the velocity of longitudinal waves.

Surface - Under certain conditions, surface or Rayleigh waves only penetrate the surface of material to a depth of one wavelength (Figure 8-6). Surface waves travel at 88 to 95 percent the velocity of shear waves and travel along the surface in an elliptical wave motion.

Plate - For very thin plates, various “plate” or Lamb waves are created (Figure 8-7). In this case the plate acts as a wave guide, through which symmetrical and asymmetrical modes can simultaneously pass. The results obtained by the use of plate waves are extremely complex, due to the dispersive velocities of the waves that may exist within the material being tested. Their application in flaw detection is limited to examination of plate, which will cause a change in the complex screen display, frequency and phase, and amplitude of signals.

8.3.7.1 Acoustic Impedance

When sound is incident at an angle normal to an interface of two media, some of the sound is reflected and some of it is transmitted. The amount of sound reflected and transmitted will depend upon the characteristic acoustic impedance of the two media.

Characteristic acoustic impedance (Z) of a material is the product of the velocity of sound through a material (V), and the density (ρ) of the material as follows:

$$Z = V x \rho \qquad (8\text{-}3)$$

8.3.7.2 Reflection at Interfaces

As mentioned in Section 8.3.4, the amount of sound reflected at an interface may be calculated by the formula:

(8-4)

$$\% \text{ Sound reflected} = (Z_1 - Z_2)^2/(Z_1 + Z_2)^2 \times 100$$

Where;

Z_1 and Z_2 are the characteristic impedances of the two media. Table 8-1 lists the acoustic impedance for various materials.

Applying the formula to a water/steel interface it can be seen that 88 percent of the sound is reflected while 12 percent is transmitted (Figure 8-2). At a metal/air interface there is virtually 100 percent reflection. This formula applies only when the two media are in intimate contact. In practice even two apparently smooth metal surfaces, in close contact, will have an air gap caused by minute surface irregularities and almost total reflection occurs.

The basis of ultrasonic flaw detection is that there is a difference in characteristic impedance between the base material and any discontinuity, whether it be a fatigue crack, a stress corrosion crack, or a metallic inclusion. If there is no change in characteristic impedance, there is no reflection of the sound wave.

8.3.7.3 Fresnel Zone (Near Field)

The sound beam radiated close to the transducer consists of a tapering near field or Fresnel zone beginning at the crystal surface, followed by a spreading far field or Fraunhofer zone.

Sound originates on the crystal surface as a number of individual point sources radiating spherical waves. As the waves progress outward, they interfere with each other (Figure 8-8).

Constructive interference occurs where waves arriving at a point in phase reinforce each other. Destructive interference occurs where waves arriving at a point out of phase cancel each other. The varying phase relationships cause varying wave amplitudes. Because of these amplitude variations, it is difficult to approximate reflector size in the near field. Eventually, the waves combine into a single spherical wave front. This occurs at the so-called Y_o point, which is the end of the near field and the beginning of the far field (Figure 8-9).

The length of the near field can be approximated by the following formula where N is near field length, D is transducer crystal diameter, f is test frequency, and V is velocity:

(8-5)

$$\text{Near Field} = D^2 \text{ (mm)} \times f \text{ (MHz)}/(4V \text{ (km/sec)})$$

As near field length varies, the position of a reflector relative to the Y_o point likewise varies. Sensitivity is optimized when the reflector is positioned near the beginning of the far field.

The near field contains areas of maximum and minimum effects. This can be demonstrated if a series of small reflectors of the same area, but at varying depths, are scanned and a graph of signal amplitude against distance is plotted. The end of the near field is the point where the amplitude is greatest.

8.3.7.4 Fraunhofer Zone (Far Field)

Beyond the near field is the Fraunhofer zone (far field) (Figure 8-9). Here the beam diverges and is referred to as beam spread. Through the far field the sound behaves similar to a beam of light, in that the sound pressure disperses according to the Inverse Square Law (i.e., the intensity is inversely proportional to the square of the distance) and travels in straight lines.

The spreading far field is characterized by a predictable decrease in sound pressure per unit area as distance from the transducer increases. Because the near field contains numerous variations in sound pressure while the far field produces predictable sound pressure, it is preferable to make sound amplitude measurements in the far field for the purpose of discontinuity severity evaluation. The angle of beam spread in the far field can be approximated by the following formula:

(8-6)

BSArc sin=1.22xV(km/sec)/D(mm) x f(MHz))

BS Arc sin is the angle of beam spread

V is the velocity of the material

D is the diameter of the transducer

F is the frequency of the transducer

Note that both the near field and beam spread formulas are based on the same variables: transducer diameter, frequency, and material velocity.

As the formulas indicate an increase in diameter and/or frequency increases near field length and reduces beam spread. Transducer diameter and test frequency, therefore, have a major effect on examination performance.

As beam spread is decreased, there is more sound pressure per unit area, thereby increasing echo amplitude. Beam spread is decreased by increasing transducer diameter and/or increasing frequency.

8.3.7.5 Dead Zone

The initial pulse is a technical necessity. It limits the detectability of near-surface discontinuities. Reflectors in the dead zone, the non-resolvable area immediately beneath the surface, cannot be detected (Figure 8-10). The dead zone is a function of the width of the initial pulse which is influenced by the probe type, test instrument discontinuities and quality of the interface.

The dead zone can be verified with an International Institute of Welding (IIW) calibration block. With the time base calibrated to 50 mm, and the transducer on position A (Figure 8-11), the extent of the dead zone can be inferred to be either less than or greater than 5 mm. With the probe at position B, the dead zone can be said to be either less than or greater than 10 mm. This is done by ensuring that the peak from the perspex insert appears beyond the trailing edge of the initial pulse start. Excessive dead zones are generally attributable to a probe with excessive ringing in the crystal.

8.3.8 Refraction

In order for the maximum amplitude from a reflector to be displayed, the axis of the sound beam must be perpendicular to the reflector. Straight beam transducers are not effective for many reflectors that are angular to the examination surface. When the largest face of the discontinuity is expected to be at an angular orientation to the surface, angle beam transducers are best suited to detect such discontinuities (Figure 8-12).

There are different ways of introducing angle beams into the material, depending on the coupling technique used. In order for angle beams to be produced, the transducer's beam must be at an angle to the surface. For contact testing, transducers are affixed to angle wedges (Figure 8-13); immersion testing permits continuously variable angulations of the transducer by means of an adjustable manipulator assembly.

Angle beams are produced using the principle of refraction. Refraction is the changing in the angular direction of a sound beam when it passes through an interface between two materials of different acoustic velocity.

Consider a sound beam aimed perpendicular to an interface. The sound beam approaching the interface is called the incident beam and is therefore identified as being incident to the interface. The angle of incidence (or incident angle*)* is the angle between the axis of the incident beam and a line drawn perpendicular to the interface.

The sound beam reflected from the interface is called the reflected beam (Figure 8-14). The angle of reflection (or reflected angle) is the angle between the axis of the reflected beam and a line drawn perpendicular to the interface at the point of sonic impact. The angle of reflection is equal to the angle of incidence.

When a sound beam is incident to an interface at an angle other than 90°, a phenomenon called mode conversion occurs. That is, in addition to the simple reflection described in the previous paragraph, a portion of the incident beam's energy converts at the interface to a beam of a different wave mode and refracts at an angle other than the angle of incidence. The angle at which the mode converted beam refracts depends on the material and is related by Snell's Law.

At certain incident angles, there may be two refracted sound beams (Figure 8-14); one is a refracted compressional wave, and another is a refracted shear wave (mode conversion).

8.3.8.1 Snell’s Law

Relationship among incident, reflected, and refracted angles depend upon the velocity relationships of the various angles and are determined by Snell’s Law:

$$\frac{\sin\alpha \text{ (Incident)}}{\sin\beta \text{ (Refracted)}} = \frac{V_1 \text{ (Material 1)}}{V_2 \text{ (Material 2)}} \quad (8\text{-}7)$$

Where;

α = Incident angle
β = Refracted angle
V_1 = Velocity in material 1
V_2 = Velocity in material 2

8.3.8.2 First and Second Critical Angles

The angle of refraction depends upon both the incident angle and the ratio of velocities for the materials through which the sound is traveling. As the incident angle increases, the refracted angles also increase (Figure 8-15). The first critical angle is the incident angle that causes the compression wave to be refracted at 90°. The second critical angle is the incident angle that causes the shear wave to be refracted 90°. For example, a plastic wedge will produce angle beams in carbon steel with the first critical angle at 27.2° and the second critical angle at 55.8°.

If the incident angle is between 0° and the first critical angle, there will be two wave modes in the material, compressional and shear. If the incident angle is between the first and second critical angles, there will be only one wave mode in the material, a shear wave.

If the incident angle is above the second critical angle, there will not be any refracted beams in the material. Surface waves, however, attain maximum amplitude in the material at an incident angle in the range of the second critical angle.

8.3.9 Ultrasonic Examination Variables

UT is versatile in application. For pulse echo examinations, indications are obtained when sound pulses transmitted into the test object reflect from surfaces such as discontinuities or the back surface of the material. Assuming that proper distance/amplitude correction has been employed, higher amplitude signals indicate reflections from larger reflectors. Pulse-echo is clearly the preferred technique because access to only one side of the object is required and specific information is available from individual reflectors.

8.3.9.1 Equipment

UT instruments are basically devices for comparing conditions in the material to a reference standard. Consequently, an ultrasonic instrument must be calibrated prior to use. Calibration is the process of adjusting the instrument to a reference standard.

Most UT instruments have A-Scan (time versus amplitude) displays. Pulse echo equipment includes hand-held thickness gages with digital display to multi-channel immersion system installations with both CRT display and recording output. Standard instruments are suitable for a wide range of detection and thickness measurement applications. These instruments display time and amplitude information on a CRT display. Optional accessory circuits include electronic distance amplitude correction, monitor gates, digital distance/thickness readouts, and mathematical calculation circuitry for use in

angle beam tests.

Ultrasonic thickness gages are similar in concept to flaw detectors except that the CRT is replaced by a digital display for thickness readout only. Data recorders are often available as accessories. However, the inability to verify echoes on a CRT is sometimes considered a limitation of digital only instruments. Some gages now have an A-scan display to verify digital data with signals.

Ultrasonic flaw detectors are considerably more versatile than thickness gages. To estimate discontinuity size, the instrument is adjusted so that a specific gain setting results in a signal amplitude produced by a known size reflector in a reference standard. To determine the difference in echo amplitude between a discontinuity signal and the reference signal, the examiner adjusts the peak of the discontinuity signal, using a calibrated gain control, to produce the same amplitude as the reference signal. The gain difference between the two signals is then noted after corrections for factors such as differences in distance and surface condition are made.

Ultrasonic instruments typically have gain controls calibrated in “decibels”, a logarithmic unit. Because sound amplitudes can vary over a wide range, decibels are used to compress this range for convenient measurement of differences in amplitude. The formula for converting an amplitude ratio to decibels is:

$$dB = 20\log_{10}(A_1/A_2) \quad (8\text{-}8)$$

The formula for converting decibels to amplitude ratios is:

$$\text{Amplitude Ratio} = \text{antilog } (dB)/(20) \quad (8\text{-}9)$$

As indicated by the formulas, decibel values are logarithmic and are added to perform multiplication and subtracted to perform division. That is, to add decibels multiply ratios; to subtract decibels divide ratios.

8.3.9.2 Transducers

In UT, the ear of the system is the transducer. After transmitting sound, the transducer hears echoes that result from the condition of the material and relays the information back to the instrument where it is visually displayed on the CRT. The capabilities of a transducer, and for the entire UT system, are for the most part described by two terms: sensitivity and resolution.

Sensitivity - The sensitivity of a transducer is its ability to detect reflections from small discontinuities. Transducer sensitivity is measured by the amplitude of its response from a reflection in a standard reference block. Precise transducer sensitivity is unique to a specific transducer. Even transducers of the same size, frequency, and material by the same manufacturer do not always produce identical indications. Transducer sensitivity is rated by its ability to detect a given size reflector, at a specific depth, in a standard reference block.

Resolution - The resolution of a transducer refers to its ability to display two signals from

two reflectors close together in the sound path. For example, a near-surface reflector and the initial pulse - the ability to resolve the near-surface reflector is a measure of resolution. If a small discontinuity just beneath the surface is masked by the initial pulse, it is not resolved.

8.3.9.3 Couplant

A liquid couplant is necessary to exclude the air and serve as a medium for transmitting ultrasonic vibrations from the transducer to the object being examined. There are two ways to accomplish this: 1) couplant is applied only to the test surface between the contact transducer (Figure 8-16) and test material, and, 2) immersion testing, where both the transducer and part or all of the test object are immersed in water (Figure 8-17).

The primary advantage of contact testing is portability. Contact testing also allows the transducer to be moved by hand over complex part geometries and requires a lower initial investment in equipment. A variety of couplants are available for contact testing. Generally, the rougher the test surface, the more viscous the couplant should be.

Immersion testing can be automated facilitating high speed examination and recording of results. Moreover, immersion tests provide uniform coupling, are virtually immune to transducer wear, and allow use of the higher frequency transducers. In general, immersion testing offers excellent control over test variables and provides results of the highest quality.

8.3.9.4 Scanning Techniques

Scanning technique is a motor skill of the examiner requiring practice and experience. Probe manipulation is related to the signals being analyzed and correlated with the unseen beam emanating from the transducer. An experienced examiner almost has a sixth sense with the transducer being his “eyes” and the CRT screen being his “vision”. A minimum of 10% overlap between scan passes is required.

8.3.9.5 Part Structure

Part structural changes can obscure areas to be examined preventing access to a particular examination area and in some cases preventing the use of UT completely. Laminations may also prevent the transmission of sound into regions of a weld. Weld exams typically require a compression wave exam of the base material that the sound will pass through to locate such laminar flaws.

8.3.9.6 Surface Condition

The rougher the surface the more viscous the couplant required and the greater the scatter of sound at the interface surface. Therefore, surface condition has a considerable bearing on sensitivity, signal-to-noise ratios, and sound transmission.

8.3.9.7 Part Geometry and Size

Part geometry can create internal mode conversion, spurious echoes, and complex CRT displays possibly masking signals from disconti-

nuities but inevitably making interpretation much more difficult. The size of the part also effects attenuation due to increased beam range, divergence, scatter, and absorption. The use of larger, lower frequency transducers can provide better sound transmission but at a sacrifice of sensitivity and resolution.

8.3.9.8 Discontinuity Type, Shape, and Orientation

The type of discontinuity, its shape, and orientation affect the amplitude of the reflected signal. Sizing is therefore a very inexact science. A discontinuity the size of the beam could result in almost no response if it were of a certain character, type, or orientation.

8.4 Equipment

8.4.1 Ultrasonic Transducers

Ultrasonic transducers behave like loudspeakers in that they convert electrical energy to mechanical energy and they behave like microphones in that they convert mechanical energy back into electrical energy.

8.4.1.1 Types

Compression - A normal incident compression probe is one which transmits a pulse of compressional sound into the specimen at right angles (normal) to its surface. Figure 8-18 shows a typical example of this type of probe.

Delay Line - In order to facilitate the complete examination of thin sections, it is necessary to eliminate the effect of the dead zone. A normal compressional probe is mounted on a perspex block so that the dead zone and part of the near field are within the perspex (Figure 8-19). A signal and multiple echoes from the perspex interface, which, by use of the delay and range controls, may be expanded on the time base so that the echoes from the material being examined appear between the first and second echoes from the delay line (Figure 8-20). These probes may be used for thickness measurement. The delay line is normally made from plastic and ordered in microseconds (μS) delay dependent upon the thickness of materials to be examined.

Dual Element (Pitch-Catch) - These probes may be either compressional or shear wave. One crystal is used as the transmitter and the other as the receiver. With compressional probes the crystals are mounted on perspex so that the dead zone and some of the near field do not exist in the material being examined, similar to the delay line probe (Figure 8-21). This increases the detect-ability of near-surface discontinuities. Dual element probes may suffer from cross-noise caused by sound interference between the two crystals since couplant can seep into the sound barrier cork material, and may result in an indication similar to a discontinuity.

8.4.1.2 Care of Transducers

Care of transducers is necessary to reduce possibilities of impact damage, excessive wear, stray electrical pulses, excessive heat, and chemical contamination. Coaxial cables are particularly vulnerable to damage and should not

be unduly bent, knotted, or twisted. Petroleum based couplants should not be used because they can deteriorate rubber components.

8.4.2 Base Pulse-Echo Instrumentation

The UT system includes: the instrument, transducers, calibration standards, and the object being examined. These elements function together to form a chain of events during a typical UT that can be summarized as follows:

- The instrument's time base initiates readout of time/distance information on the horizontal scale of the display.
- The instrument's pulser electrically activates the transducer, causing it to send sound pulses into the test object. The activation signal, called the initial pulse, is displayed as a vertical signal on the CRT.
- As sound travels through the test object, it reflects from boundaries as well as from discontinuities within the material. A reflection from the surface opposite the entry surface is called a back reflection.
- These reflections reach the transducer, which converts them into electrical signals that are displayed on the CRT.

Understanding the operation of UT equipment may be simplified by referring to a sample block diagram of an analog instrument (Figure 8-3). A basic instrument contains several circuits: power supply, clock (also called synchronizer or timer), time base (called sweep generator), pulser (also called transmitter), receiver (also called receiver-amplifier), and the display.

8.4.2.1 Time base

The function of the time base, also called "sweep generator" in analog-display instruments, is to establish a display of sound travel time on the horizontal scale of the display. The horizontal scale can then be used for distance readout. The range (coarse range, test range) control adjusts the scale for the range of distance to be displayed.

For digital flaw detection instruments, there is no sweep generator in the analog sense. Instead, the horizontal axis of the display is comprised of a series of divisions (usually about 200 dots are used in the horizontal direction of the display). Each division represents an increment of time. The amount of time represented by each division is controlled by a complex combination of software and hardware.

In order to establish a calibrated range for a particular test, the sound velocity of the material must be known or measured and entered into the instrument. Then when the appropriate zero offset has been entered, range settings are in absolute units of metal path distance. As the range is increased, the time interval represented by each of the horizontal dots becomes larger. For very large ranges, one division may represent an entire echo waveform. For smaller ranges, the same echo waveform is represented by several divisions and the shape of the echo waveform then becomes apparent. The important thing to remember is that in a digital instrument where the waveform has been converted from an

analog signal to a digital waveform, the number of points across the horizontal remains fixed and the time interval represented by each division changes as the range is adjusted.

8.4.2.2 Clock

The clock circuit initiates a chain of events that results in one complete cycle of a UT examination. The clock sends a trigger signal, at a regular interval, to both the time base and to the pulser. As the name “clock”' implies, this trigger signal is repeated at a given frequency, called the pulse repetition rate. On some instruments pulse repetition rate is adjustable by the examiner; other instruments do it automatically.

8.4.2.3 Pulse Repetition Rate

The pulse repetition rate establishes the number of times per second that a complete test cycle will occur. In instruments with adjustable pulse repetition rate, adjustment is made by a pulse repetition rate control, sometimes labeled REP RATE. Greater sound travel time requires a longer test cycle and a lower pulse repetition rate to provide the longer test cycle or interval.

8.4.2.4 Pulser-Receiver

The pulser emits the electrical signal that activates the transducer. This signal, known as the initial pulse, is quite brief, usually lasting only several nanoseconds (billionths of a second). The output of the initial pulse is in the order of hundreds of volts; the brief duration provides a fast rise time to the full voltage. The pulser is connected via output connectors on the instrument front panel to the transducer cable. The pulser is also connected, internally, through the receiver circuit, to the display, thus making available (depending upon the delay setting) a displayed initial pulse signal. This signal is, of course, present whether or not a transducer is connected to the instrument.

When a transducer is connected, it is in the signal path between the pulser and the receiver and its output is displayed.

8.4.2.5 Basic Controls

The amplifier multiplies the voltage of signals passing through it in order to provide adequate signal amplitude. The amount of voltage multiplication, or amplification, is controlled by gain controls. Calibrated gain controls are adjustable in discrete units of decibels (dB), the unit of measure for gain multiplication. Calibrated gain controls are intended for making decibel amplitude comparisons between reference standard amplitudes and the amplitudes of signals returning from the test material.

The REJECT control is intended for preventing the display of undesired low amplitude signals, called grass or hash, caused by metal noise such as echoes from material grain boundaries or inherent fine porosity (Figure 8-22). There are two types of REJECT controls installed on UT instruments: nonlinear REJECT and the more recently linear REJECT controls. Linear REJECT controls offer the advantage in that they do not affect vertical

linearity of the display.

Controls marked DELAY and RANGE are used to adjust the instruments *time base* for proper display of distances. The delay control shifts the vertical signals to the left and right without altering the spacing between them. The RANGE control expands or contracts the spacing between vertical signals, corresponding to the Range of the sound travel to be displayed.

The sound amplitudes of individual reflectors returning to the transducer determine the relative heights of the corresponding vertical signals on the CRT. The GAIN control adjusts vertical display sensitivity and therefore determines the actual amplitude at which signals are displayed.

If the signal height of different size flat bottomed holes located at the same distance from the test surface are compared, the signal heights will be proportional to the reflecting areas of the holes. However, if a flat bottomed hole of an identical reflecting area is located at a different depth from the test surface, it will produce a lower amplitude signal.

8.4.2.6 Gates

Most UT equipment is equipped with “gates” that can be superimposed on the time base so that a rapid response from a particular reflector can be obtained when they reach a certain predetermined amplitude. This can be adapted as a “go/no-go” monitoring device for some examinations. Gates can be set for an alarm to be triggered at a pre-determined amplitude (positive) with an increasing signal or (negative) with a decreasing signal amplitude. Gates are essential for some types of recording systems where they also serve to provide information to the recording devices or storage systems.

8.5 Procedure

UT is performed in accordance with an approved procedure. Each procedure should include at least the following information and any information listed in the Essential and Nonessential variables in section V:

- Weld types and configurations to be examined, including thickness dimensions, materials, or product form (casting, forging, plate, etc.);
- The surface or surfaces from which the examination should be performed;
- Surface condition;
- Couplant;
- Technique (straight beam, angle beam, contact and/or immersion);
- Angles and mode(s) of wave propagation in the material;
- Search unit type, frequency, and transducer size(s);
- Special search units, wedges, shoes, or saddles, if used, and type and length of search unit cable;
- Ultrasonic instrument type(s);
- Description of calibration blocks;
- Directions and extent of scanning;
- Data to be recorded and method of recording (manual or automatic);
- Automatic alarm and recording equipment, or both, if used;

- Rotating, revolving, or scanning mechanisms, if used;
- Personnel qualification requirements; and
- Review or qualification of the procedure as required by the referencing Code section.

8.5.1 Application of the Various Wave Modes

To obtain maximum reflection amplitude in a pulse echo examination, the sound beam must be perpendicular to the discontinuity detected. When this discontinuity is parallel to the sound entry surface, a compressional wave transducer provides the best response. When the discontinuity is obliquely oriented to the surface, the sound beam must enter the material at an angle that orients the beam perpendicular to the discontinuity.

8.5.1.1 Compressional Wave Applications

Plate - Straight beam approach is best for detection of laminations.

Thickness - A wide range of materials and thickness, as well as corrosion/erosion can be measured very accurately.

Bar - Central axial inclusions, piping and other discontinuities can be detected with a simple compressional wave technique.

Castings - Porosity, gas holes, inclusions, shrinkage, and other typical casting discontinuities can be detected. Major limiting variables include surface finish, configuration, and grain structural.

Forgings - Grain-orientated discontinuities, bursts, and flake are readily detected.

8.5.1.2 Shear Waves

Pipe and Tubing - Radial longitudinal or circumferential discontinuities caused by stress corrosion and fatigue can be detected.

Welds - The more serious planar type discontinuities including lack of fusion, incomplete penetration, and cracks are best detected with shear wave techniques.

8.5.1.3 Surface Waves

Surface waves can propagate around corners and radii of holes to successfully detect otherwise inaccessible discontinuities at the surface.

8.5.1.4 Lamb Waves

Lamb waves are best for detecting lamination and other discontinuities in a thin sheet.

8.5.2 Immersion Testing

8.5.2.1 Immersion Tanks and System Components

Immersion systems consist of a bridge and manipulator, mounted on a water tank, a pulse echo instrument and a recorder as shown in Figure 8-23. Drive units move the bridge along the tank side rails, while transversing units move

the manipulator from side to side along the bridge. Most of these units are automated, although some early units are manually operated.

The ultrasonic tank may be of any size or shape required to accommodate the test specimen. Coverage of the specimen by a foot or more of water is usually sufficient. Adjustable brackets and lazy-susan turntables are provided on the tank bottom for support of the test specimen. The water in the tank is clean, de-aerated water containing a wetting agent. The water temperature is usually maintained at ambient temperature.

Manipulators - The manipulator is primarily intended to provide a means of scanning the test specimen with an immersed transducer (Figure 8-24). The manipulator is mounted on a traversing mechanism, which allows movement of the manipulator from side to side. The traversing mechanism is an integral component of the bridge assembly. A search tube is usually held rigid at right angles to the surface of the test specimen. Locking knobs are provided on the manipulator to allow positioning of the search tube in two planes for angle-beam testing.

Bridges - When the manipulator is automated, electric motors are added to power the bridge carriage, the traversing mechanism, and the up and down movement of the search tube. The pulse-echo unit and the recording unit are also mounted on the bridge, with all power cords secured overhead to allow movement of the bridge along the full length of the tank.

Wands - The support tube for the immersion probe is sometimes called a wand. Its vertical height can be adjusted to vary water path distance and the adjuster which can manipulate probe angle of incidence at the tip of the wand.

8.5.2.2 Immersion Transducers

Flat - The flat transducer operates under the same considerations as regular compressional transducers, except it does not have a protective face, and it is waterproof. Near fields for these probes are, of course, often four times greater due to the slow water velocity compared to steel.

Focused - An acoustical lens is fitted to the front of the transducer. Focused probes can be manufactured to produce any focal length. Often focused single axis, focused transducers allow high resolution examination of immersed shafts (converging parallel focus) or tubing from the inside (diverging parallel focus).

Frontal units shaped to direct the sound energy perpendicular to the surface at all points on curved surfaces and radii are known as contour-correction lenses. These cylindrical lenses sharpen the front-surface indication by evening out the sound-travel distance between the transducer and the test surface. A comparison of flat and contoured transducers is shown in Figure 8-25.

Other acoustic lenses focus the sound beam from the transducer, much as light beams are focused. Focused transducers concentrate the sound energy into a long, narrow, blunt-pointed beam of increased intensity, which is capable of detecting very small discontinuities in a

relatively small area. Focusing the sound beam moves its point of maximum intensity toward the transducer, but shortens its usable range. The test specimen has the effect of a second lens; in this case, the beam is defocused, as shown in Figure 8-26. Defocusing increases intensity which produces increased sensitivity; also, moving the point of maximum intensity closer to the transducer (which is also closer to the test surface) improves the near-surface resolution. The disturbing effects of rough surface and metal noise are also reduced by concentrating the sound energy into a smaller beam. This is true simply because a smaller area is being looked at. In a smaller area, the true discontinuity indications are relatively large compared to the combined noise of other nonrelevant indications. The useful thickness range of focused transducers is approximately 0.010 to 2 inches.

8.5.3 Data Display

UT instruments present examination data in various ways. Display media include CRTs, paper chart recorders, digital readouts, and audible/visual alarms. Three basic types of displays are designated: A-Scan, B-Scan, and C-Scan.

8.5.3.1 A-Scan

A-Scan shows distance/time information as the points where signals deflect vertically from the horizontal baseline. Size/amplitude information is displayed as the height of the vertical deflections.

Sound travels at different speeds in different materials. However, the speed of sound is constant in a uniform medium. This means that sound will complete a round trip through a specific distance in a specific amount of time. It is therefore possible to measure distance by measuring sound travel time.

8.5.3.2 B-Scan

B-Scan is a pictorial presentation (Figure 8-27). The display screen shows a side view of the test object, displaying the profile of interfaces reflecting the sound beam. B-Scan can show the distance of a discontinuity from the transducer, as well as discontinuity length along the direction of transducer travel.

8.5.3.3 C-Scan

C-scan equipment is intended to provide a permanent record of the examination when high-speed automatic scanning is used. C-scan equipment displays the discontinuities in a plan view, but provides no depth or orientation information.

The most commonly used recorders use a chemically treated paper that is passed between a printing bar and a helix equipped drum as shown in Figure 8-28. The printing bar has a narrow edge and is connected electrically to one of the output terminals of the amplifier in the ultrasonic test unit. The other terminal of the amplifier is connected to the helix mounted on the drum. As the drum turns, the contact point between the bar and the helix moves back and forth across the paper. Variations in electric current at the contact point determine the amount of print-out produced on the paper. One revolution of the

drum produces one line of scan. The forward movement of the paper is synchronized with the forward movement of the transducer along the test surface. The amplifier is also connected to the oscilloscope so that, whenever a signal of predetermined amplitude is displayed, a change of current occurs in the printing bar contact. In this manner, a record of the discontinuities is produced as the transducer scans the test surface.

The C-scan recording indicates the projected length and width of the discontinuity and the outline of the test specimen as if viewed from directly above the specimen. The C-scan recording does not indicate the depth of the discontinuity in the test specimen. Some recorders produce a shaded scan line to indicate the outline of the discontinuity. On others, the discontinuity outline may be indicated by the absence of the scan lines (Figure 8-29), where the white (no line) areas represent the discontinuities.

8.5.4 Calibration Techniques

Calibration should include the complete ultrasonic examination system. The original calibration should be performed on the basic calibration block (Figure 8-30). Checks should be made to verify the sweep range/distance calibration (Figure 8-31).

In all calibrations, it is important that maximum indications be obtained with the sound beam oriented perpendicular to the axis of the side-drilled holes and notches. The center line of the search unit should be at least 1½ inches from the nearest side of the block (rotation of the beam into the corner formed by the hole and the side of the block may produce a higher amplitude at a longer beam path; this beam path should not be used for calibration). For contact examination, the temperature of the examination and basic calibration blocks should be within 25^{o} F. For immersion examination, the couplant temperature for calibration should be within 25^{o} F of the couplant temperature used in actual scanning or appropriate compensations for angle and sensitivity change should be made.

8.5.4.1 Linearity

Screen Height Linearity - The ultrasonic instrument should provide linear vertical presentation within ± 5 percent of the full screen height for at least 80 percent of the calibrated screen height (base line to maximum calibrated screen point(s)). The procedure for evaluating screen height linearity is normally provided and should be performed at the beginning of each period of extended use (or every 3 months, whichever is less) for analog units and every 12 months for digital units.

Amplitude Control Linearity - The ultrasonic instrument should utilize an amplitude control, accurate over its useful range to ± 20 percent of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen. The procedure for evaluating amplitude control linearity is normally provided. The calibration time limits are the same as for Screen Height Linearity.

8.5.4.2 Distance Amplitude

By comparing reflectors in the far field with reference reflectors, and by applying distance laws and correcting for material loss attenuation, the reflecting area of reflectors in the far field can be estimated. The narrowness of the sound beam at the beginning of the far field applies more sound pressure per unit area to reflectors, thus optimizing sensitivity. Using laws of distance, loss of echo amplitude can be calculated as same size reflectors are moved outward along the sound beam axis in the far field (Figure 8-32). There are two rules of distance; one rule for infinite reflectors and one for small reflectors.

An infinite reflector intercepts the entire sound beam. The echo amplitude of an infinite reflector is inversely proportional to distance. As the distance to an infinite reflector is doubled, echo amplitude decreases six decibels.

A small reflector intercepts only a portion of the sound beam. The echo amplitude of a small reflector is inversely proportional to the square of distance. As the distance to the small reflector is doubled, echo amplitude decreases 12 dB.

When the amplitude of a small disk-shaped reflector at 3 inches of depth is compared to an echo from the same size reflector at 6 inches of depth (Figure 8-33), the echo returning from 6 inches of depth will be 12 dB lower. That is, the echo from 6 inches of depth will have 25 percent of the echo height of the echo from 3 inches of depth.

In addition to amplitude losses resulting from beam spread, there are also amplitude losses caused by the structure of the test material. This form of attenuation results from scattering of sound by coarse grain structure or fine porosity or from conversion of sound into heat by absorption. Material loss attenuation tends to occur at a linear rate. That is, material losses occur at a rate of a certain number of decibels per linear unit of measure; for example, a rate of 1 dB per inch.

Thus, if there are two small disk-shaped reflectors of the same size, one at 3 inches of depth, the other at 6 inches of depth, and the rate of material loss is 1 dB per inch, the echo from 6 inches of depth will be 15 dB weaker than the echo from 3 inches of depth. Of the 15 dB of sound loss, 12 dB are lost because of beam spread and 3 dB are lost because of material losses.

In order to estimate reflector severity, some correction must be made for echo amplitude variations caused by distance factors. One method is to construct a DAC curve on the display screen (Figure 8-34). This is done by marking on the display the echo peaks from a given size reflector at a series of depths. The reflector used for this procedure is normally one that represents the "critical discontinuity size", the maximum acceptable reflector amplitude. A more convenient solution is to use electronic distance amplitude compensation, whereby the test instrument can be adjusted to correct echo amplitudes for distance variations.

8.5.4.3 Resolution

Resolution can be established using either the IIW block (Figure 8-35) or other blocks manufactured specifically for that purpose. The resolution capability of a particular probe/instrument combination can also be objectively determined with a step wedge. The resolution can be determined by locating the thinnest step that can be resolved.

8.5.4.4 Beam Profile

The beam width can be plotted by scanning across a suitable small reflector (transverse hole) at the depth required. The signal is maximized from the reflector and set to approximately mid-screen height (50 percent full screen height (FSH)) and the signal amplitude increased by 20 dB then scanned away from the reflector until the signal returns to pre-set amplitude. The surface is marked at the probe index (probe center for compressional probes), then scanned in the opposite direction and marked on the surface again. The distance marked is the 20 dB beam width at the depth checked. Both shear wave and compressional wave transducer widths can be plotted by this approach.

8.5.4.5 Test Block Parameters

The basic calibration block(s) containing basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude correction curve is typically as shown in Figure 8-34. The basic calibration reflectors should be located either in the component material or in a basic calibration block.

8.5.5 Unacceptable Techniques

8.5.5.1 Scanning Problems

An unacceptable scanning problem prevents discontinuities from being located with high reliability. Generally, the use of a calibration specimen with an artificial reflector matching the object under examination, proves the scanning efficiency. An unacceptable example of this would be a curved surface of a tube being examined with a flat probe. Scanning would be difficult since signal transmission is intermittent and probe handling very critical.

8.5.5.2 Interpretation Shortcomings

Interpretation shortcomings are frequent. Most originate from mode conversion signals interfering with actual discontinuity signals, or from incorrectly calibrated time base. Inexperience is always identified in this area as demands can be quite complex.

8.5.5.3 Report Format Problems

Non-standardized reports give rise to missing information. Comprehensive information on reports is essential to prevent plant down times until the missing information is found. Another problem relates to ambiguities in drawings in text that can also result in incorrect decisions or extended down times.

8.6 Interpretation and Code Requirements

8.6.1 Weld Calibration Stanards

To maintain the integrity of any UT examination it is necessary to regularly verify the performance of the equipment. This section describes the methods used to calibrate and check the performance of UT instruments and probes.

Calibration Blocks - Figures 8-35 and 8-36 show calibration blocks recommended by common standards/specifications. These are normally manufactured from steel but can also be made from other materials to suit specific examination requirements.

NOTE: English unit blocks are dimensional in inches but are not precisely the same as metric blocks. For each "25 mm" read "1 inch" (actual 25 mm = 0.98425 inches.)

Sensitivity - A broad definition for ultrasonic sensitivity is the ability of the system to be able to detect and display a response from the smallest reflector. Sensitivity is primarily influenced by the wavelength, the transducer, and the characteristics of the material being examined. As frequency increases, wavelength decreases, which results in an increase in sensitivity.

Time base Linearity - This UT instrument check is carried out to ensure that there is a linear relationship between the time base position of signals and distance. The check is carried out using a compressional probe to obtain a bottom echo with multiples and ensuring that they are equally spaced along the time base.

Resolution - Compression Transducers. This check can be conducted on the A2 block as shown in Figure 8-35.

Shear Wave Probes - This check is done by resolving the steps of the A7 block (Figure 8-36).

Beam Exit Point - To check the beam exit point (probe index) of a shear wave probe, it is placed on the A2 block and aimed at the 100 mm radius. When the signal is maximized, the exit point should align with the center of the scale, which is the center of the 100 mm radius (Figure 8-37).

Refraction Angle - The refraction angle (beam angle) of a shear wave probe is checked on the A2 block as shown in Figure 8-38 a, b, and c. The angle is measured by noting the angle that aligns with the probe index when the signal is maximized. The actual refracted angle should fall within the designated probe angle ±2°.

Compression Probes - To calibrate the time base to 100 mm of steel, the probe should be placed on the 25 mm thick portion of the A2 block and the bottom echo positioned at 2.5 on the time base with repeats at 5.0, 7.5, and 10. The length of the time base now represents 100 mm of steel. Similarly the time base can be calibrated to any suitable distance by obtaining a back echo and repeats from any of the dimensions of the calibration blocks.

Shear Wave Probes - Figures 8-39, 8-40,

and 8-41 show methods of calibrating the time base for shear wave probes. That part of the ultrasonic beam that is within the wedge is delayed off the CRT to set the transmission point to zero.

8.6.2 Evaluation

8.6.2.1 False Indications

Couplant - Couplant can cause false indications during buildup on the front of shear wave probes, particularly those probes of high angles 70° to 90°. When working in thin materials, typically weldments of ½ to ¾ inches or less, false indications may become apparent from couplant.

Spurious Electrical - Electrical interference is normally easily interpreted. "Ghost" signals moving across the CRT screen or standing signals are fairly common. These are easily identified because they have no correlation with probe motion.

8.6.2.2 Nonrelevant Indications

Part Geometry - Part geometry creates the majority of nonrelevant indications. These indications come from the reflections boundaries and other "built-in" reflectors.

Surface Irregularities - Surface irregularities can also cause signals that are nonrelevant. Weld crowns and roots are particularly a common source of reflected signals that could be misinterpreted. Provided access is available, dampening of these signals by placing the finger at the reflection point on the specimen is a good way to confirm their non-relevance.

Intergranular Reflectors - Intergranular reflectors are only found on coarser grained materials. Reflector sizes are even and distributed throughout the materials. Reduced gain settings or cautious use of the REJECT control should be considered.

8.6.2.3 Relevant Discontinuity Indications

Amplitude - Amplitude of relevant discontinuity indications has to be carefully monitored. Often some careful probe manipulation and extra use of couplant increase the amplitude, so care must be taken.

Length - Length must be plotted using some objective measuring system. Commonly 6 dB or 20 dB drop methods are utilized to achieve some degree of accuracy in sizing.

Signal Shape - Shape helps to determine the type of discontinuity. For example, a fatigue crack gives a sharp single peak, whereas wormhole porosity gives a broader and much more varying attenuated signal in comparison.

Orientation - Orientation must be determined by angulating the probe, maximizing the signal and plotting reflector position from maximum signal response positions along its length. To avoid missing signals, angulations should be constantly adjusted in a sweep motion of the beam during scanning. This allows for differing discontinuity orientation.

Location - Range calibration must be accurate to correctly locate the discontinuity in the beam path. Plotters and scale cross sectional drawings help to locate a discontinuity.

8.6.3 Recording

8.6.3.1 Use of Examination Forms

Examination forms are generally designed to meet the requirements of the code or specification. In all cases, however, examination forms are necessary.

8.6.3.2 Recording Techniques

The following techniques are or have been in use for recording UT signals:

- Cross sectional and plan drawings with plotted discontinuity locations,
- Computer recorded ultrasound signals with XY plot positions,
- C-scan recordings,
- Zip scan recordings,
- Delta scan recordings,
- P-scan weldment recordings, and
- Plotting directly on specimens or components.

In all cases, however, it is the code or specification that determines the techniques of recording.

8.7 Advantages and Limitations of Ultra sonic Examination

8.7.1 Advantages

UT has the following advantages:

- Penetration is relatively deep in a given material.
- Much of the equipment is portable, light-weight, and battery powered.
- Access to only one side of the material is required in most cases.
- Measuring thickness and locating discontinuities is highly accurate.
- It has the capability for volumetric examination.
- It is suitable for go/no-go conditions.
- There is no danger from radiation or other such hazards.

8.7.2 Limitations

UT also has several limitations:

- The test object must be able to support the propagation of sound without excessive losses.
- A liquid couplant is required to conduct sound between the ultrasonic transducer and specimen.
- The interpretation requires a highly trained and experienced examiner.
- Discontinuities just beneath the surface (dead zone) may not be detectable.
- Discontinuity orientation is a factor that requires careful technique development.

- Surface conditions must be considered.
- Part shape/configuration can be a limitation.

Table 8-1 Acoustic Properties of Materials

Acoustic Properties of Materials

		LONGITUDINAL WAVES		SHEAR (TRANSVERSE) WAVES		SURFACE (RAYLEIGH) WAVES	
MATERIAL	DENSITY $P = GM/CM^3$	VELOCITY V_L = CM/μSEC	IMPEDANCE $Z_L = GMX\ 10^3/CM^2 - SEC$	VELOCITY V_T = CM/μSEC	IMPEDANCE $Z_T = GCX/CM^2 - SEC$	VELOCITY V_R = CM/μSEC	IMPEDANCE $Z_R = GMX\ 10/10^3\ CM^2 - SEC$
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	0.56	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	765
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	0.216	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	-	-

Figure 8-1 Wavelength

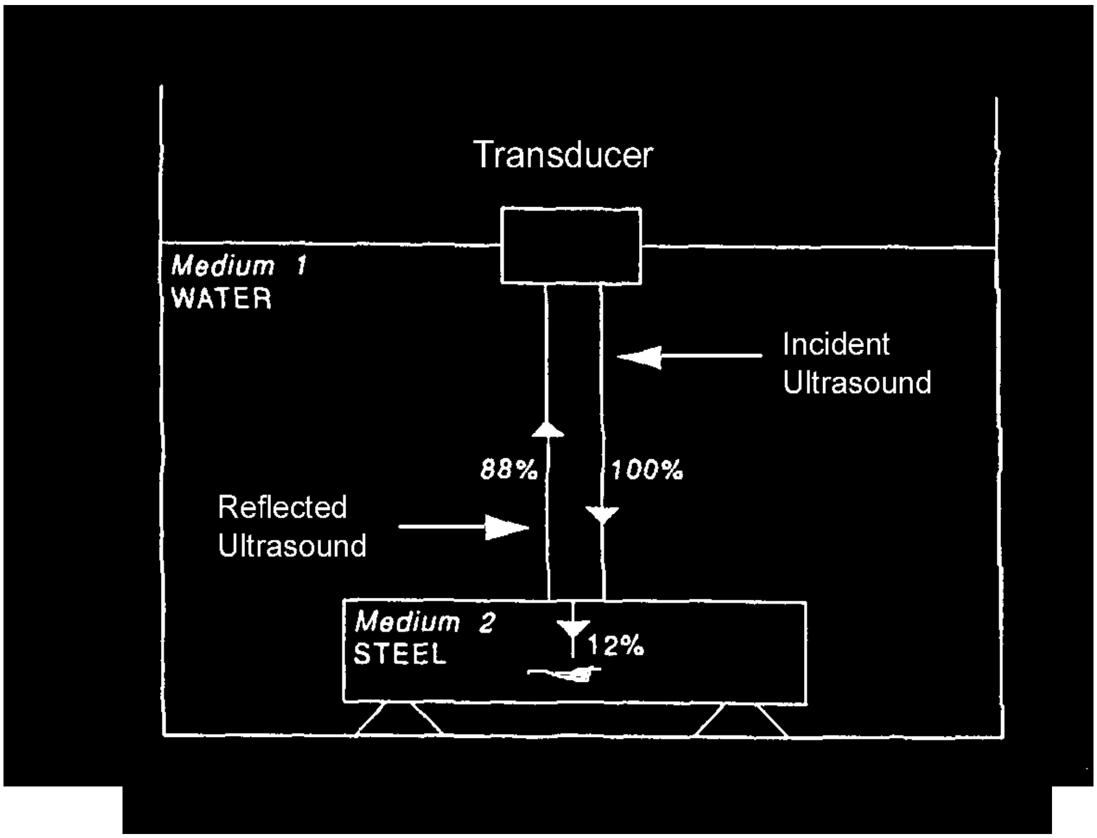


Figure 8-2 Reflection, Transmission at an Interface (Immersion Testing with Pulse/Echo Technique)

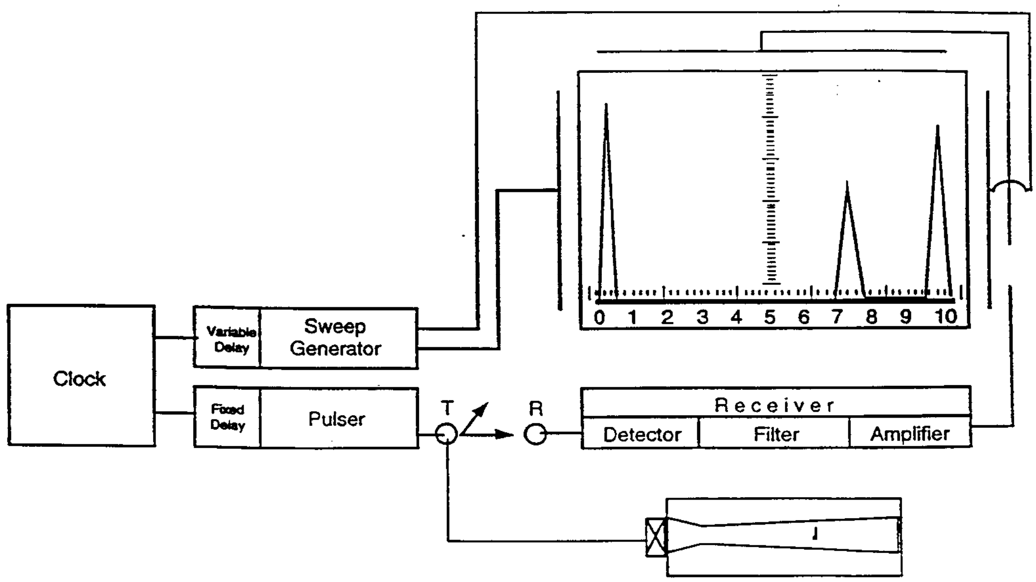


Figure 8-3 Block Diagram of a Typical Ultrasonic Instrument

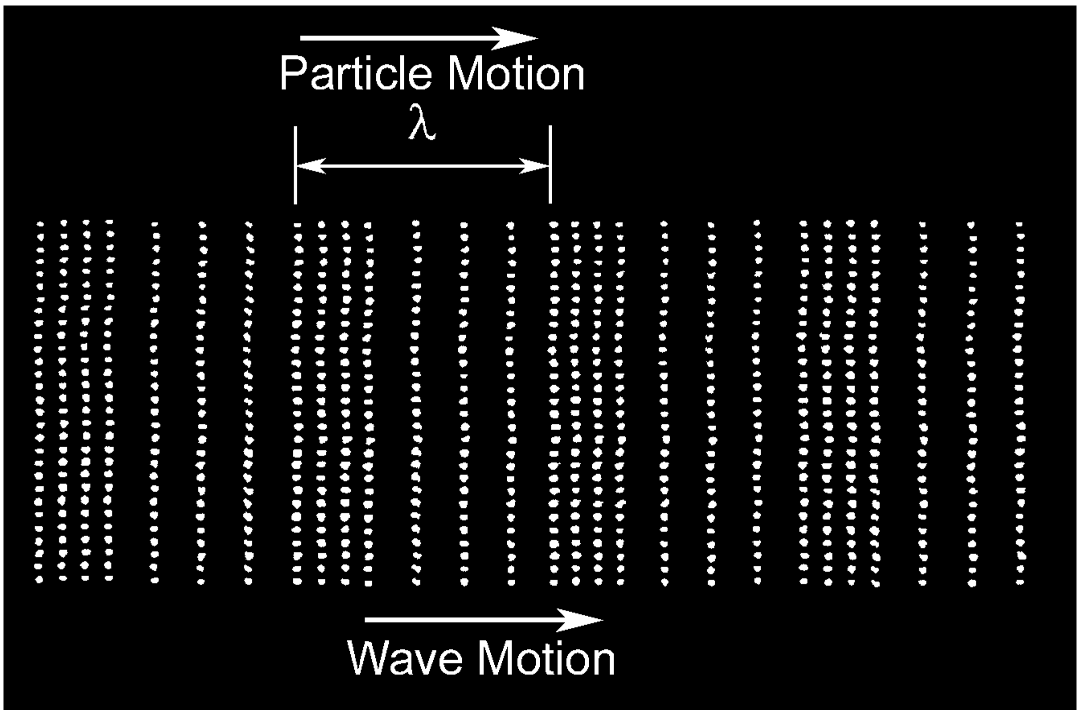


Figure 8-4 Particle Displacement by Longitudinal Waves

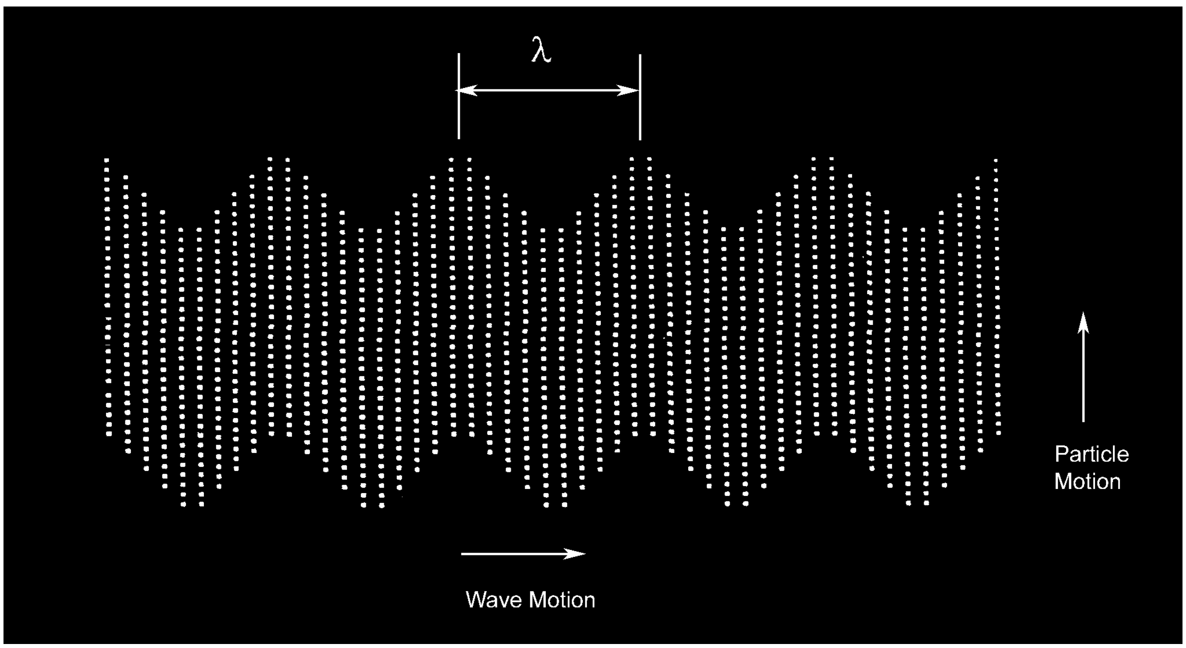


Figure 8-5 Particle Displacement by Transverse Waves

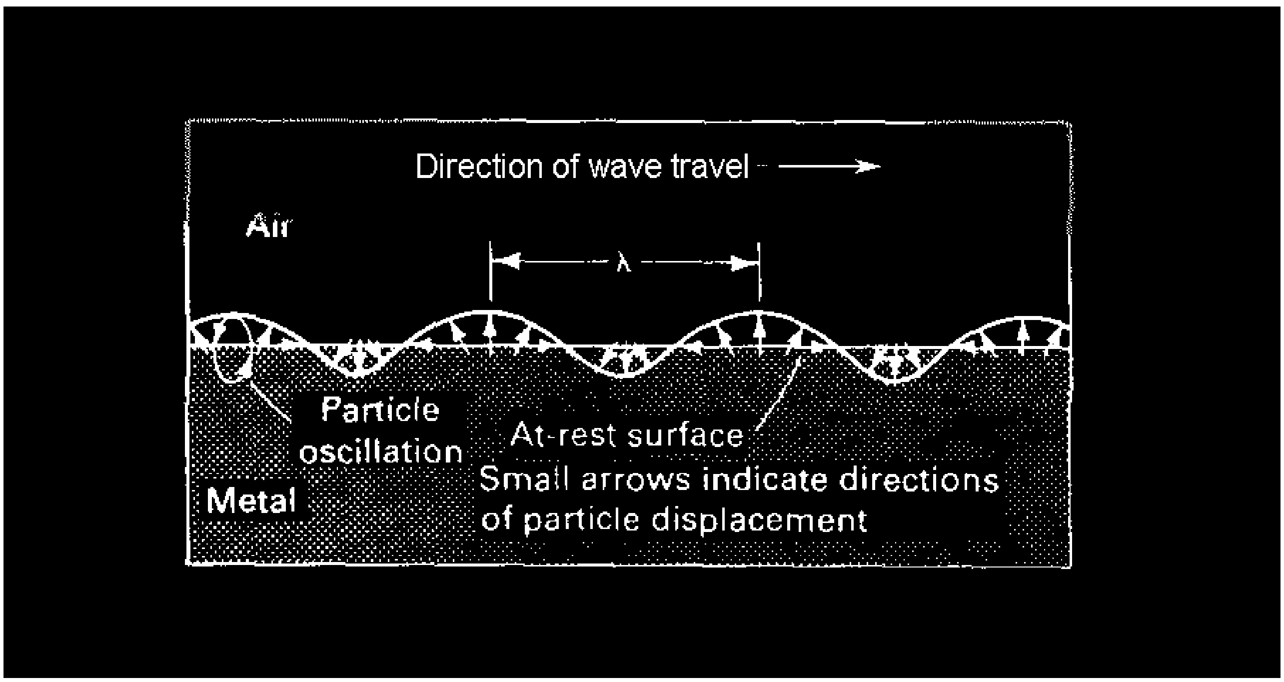


Figure 8-6 Surface or Rayleigh Wave Modes

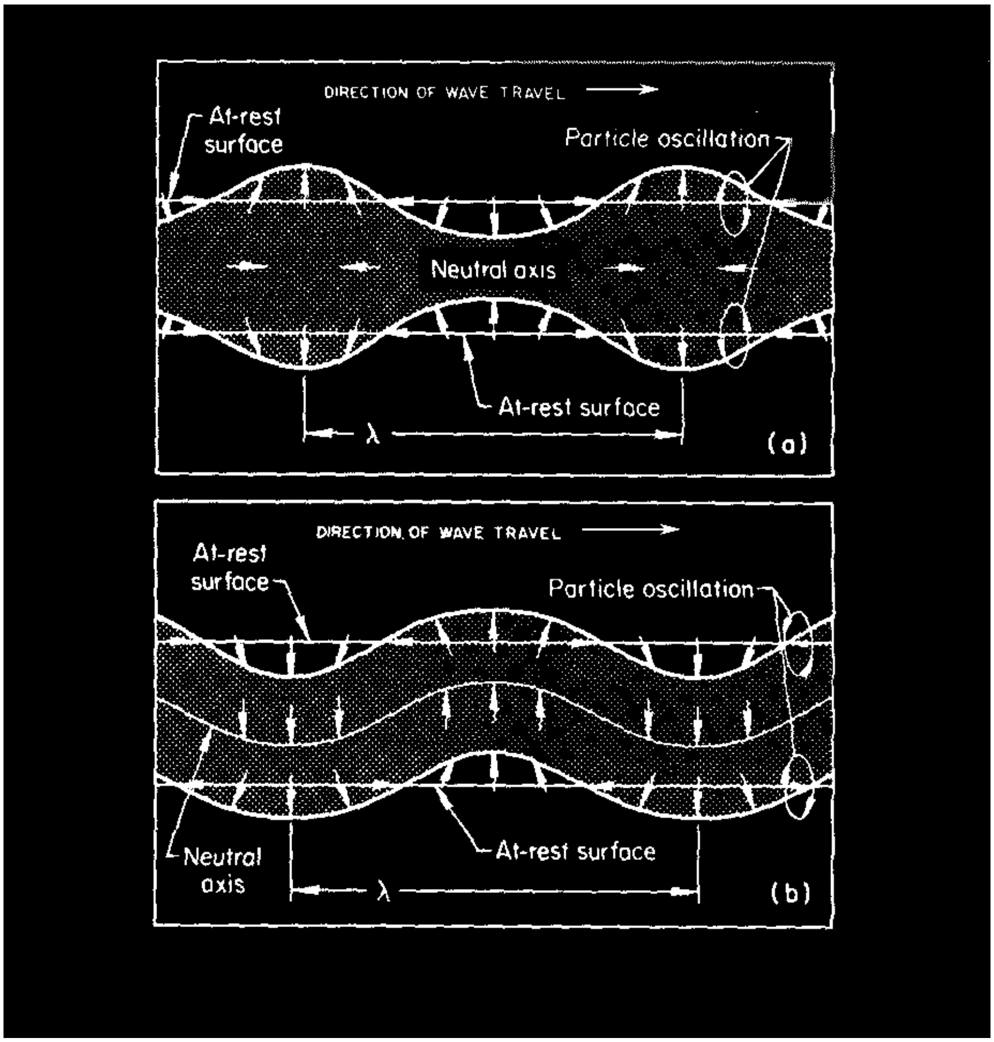


Figure 8-7 Plate or Lamb Wave Modes

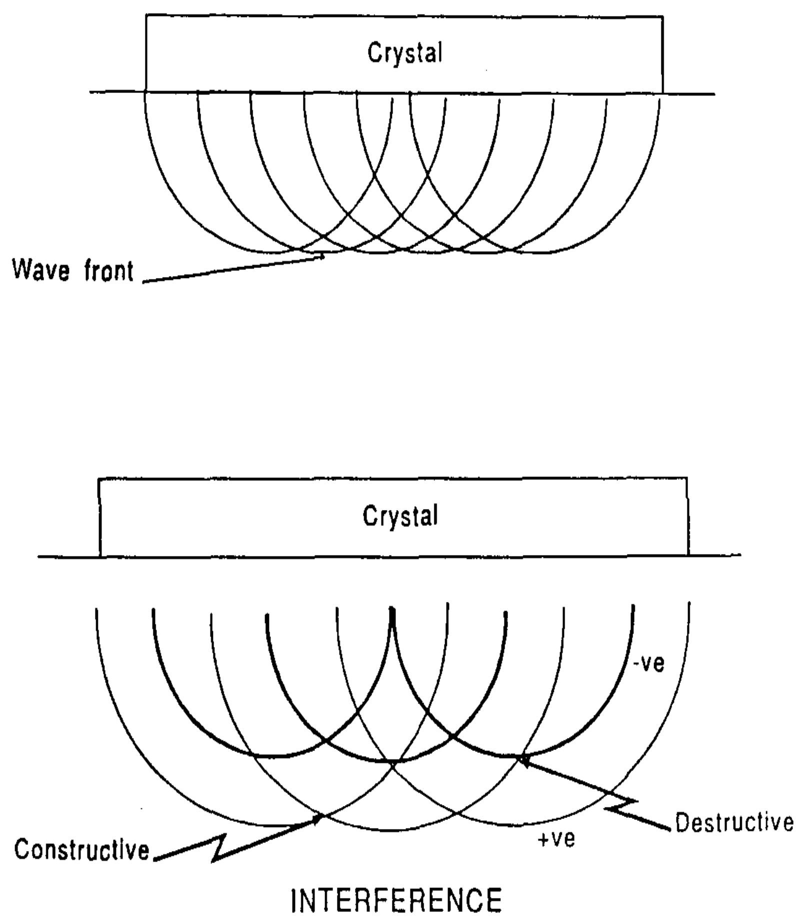


Figure 8-8 Constructive and Destructive Interference

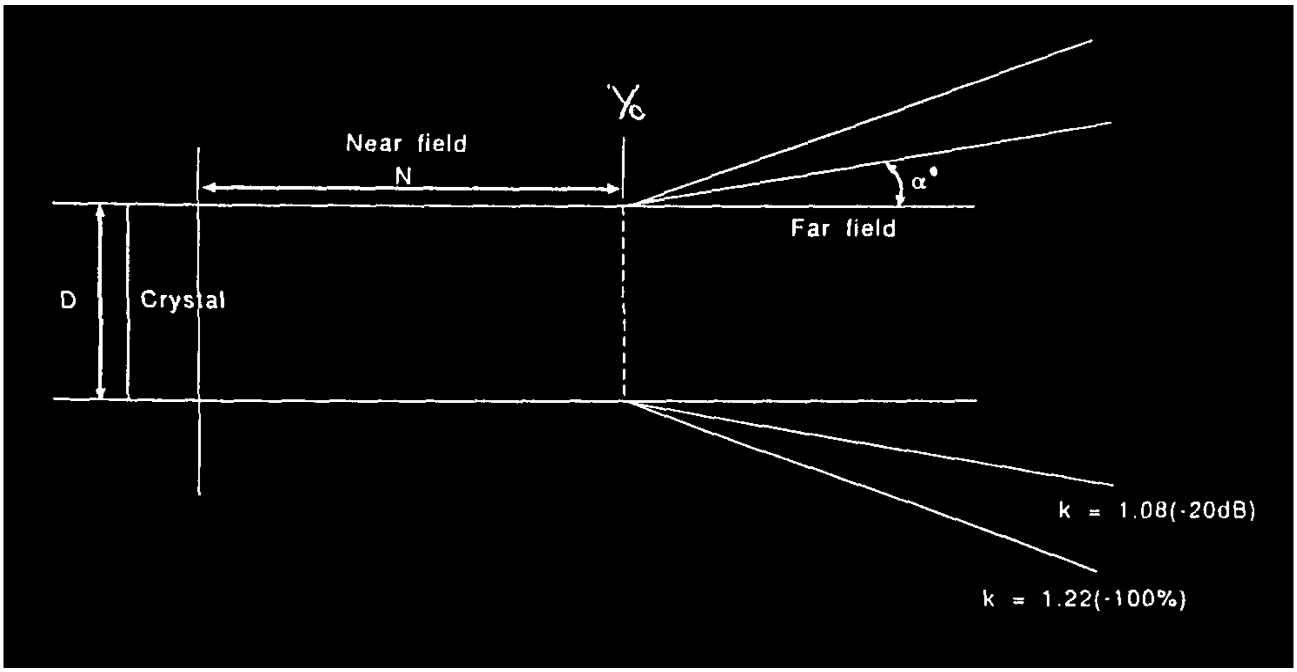


Figure 8-9 Near and Far Fields

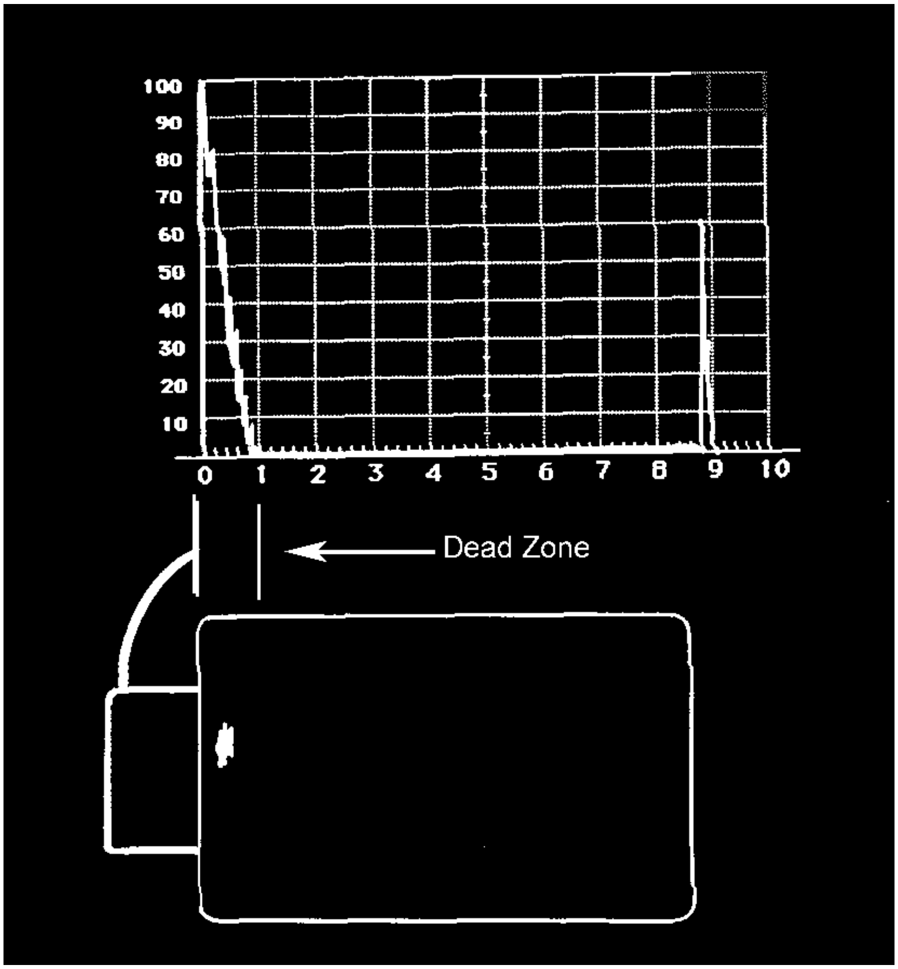


Figure 8-10 Near-to-Surface Reflector Within Dead Zone

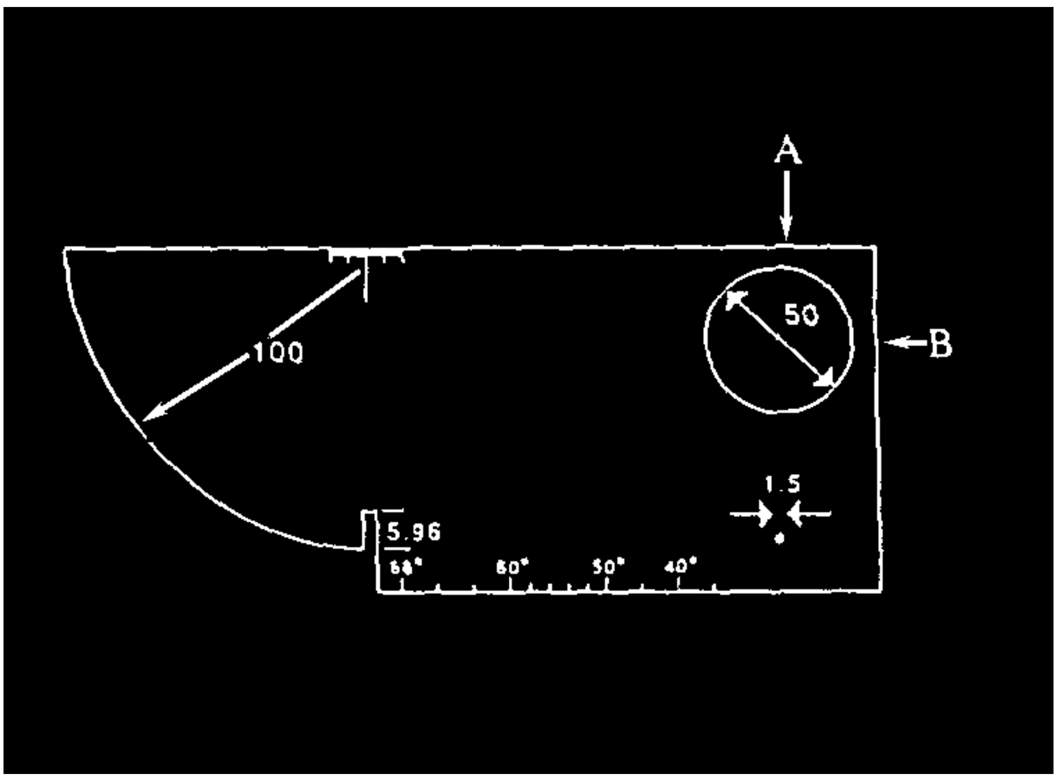


Figure 8-11 Dead Zone Check

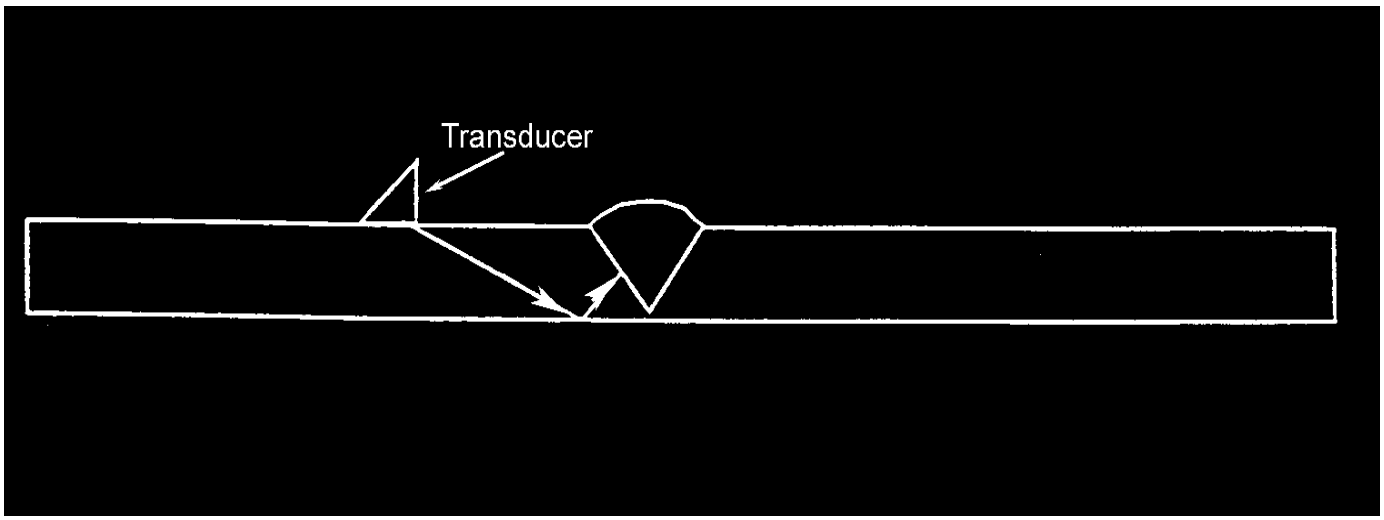


Figure 8-12 Angle Beam in Weld

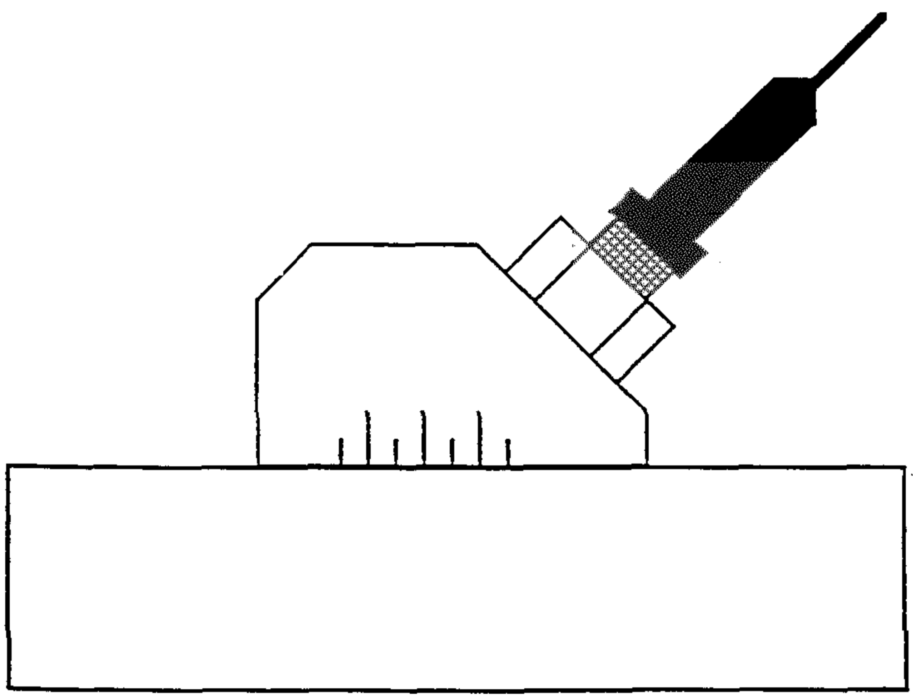


Figure 13 Angle Beam Transducer Assembly

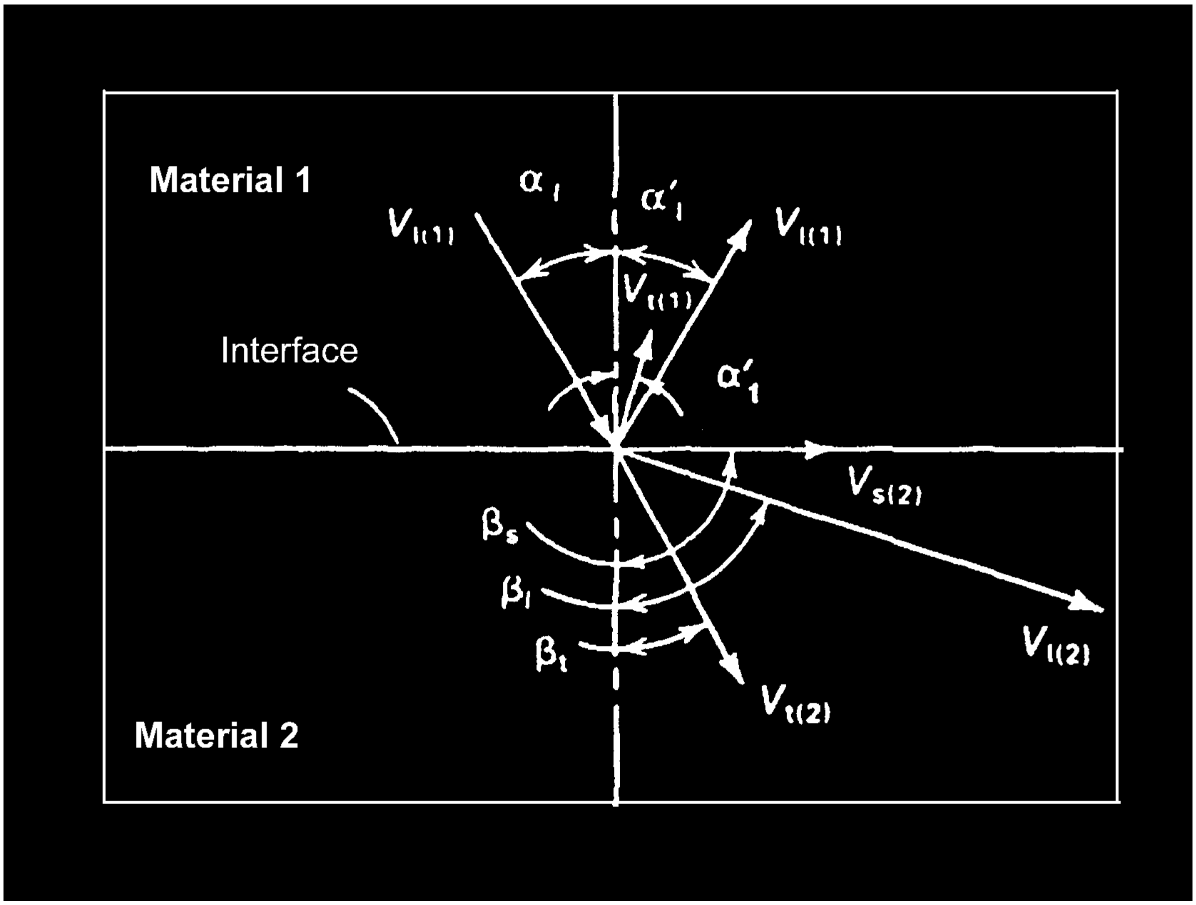


Figure 8-14 Refraction and Reflection of Incident Compressional Wave at an Interface

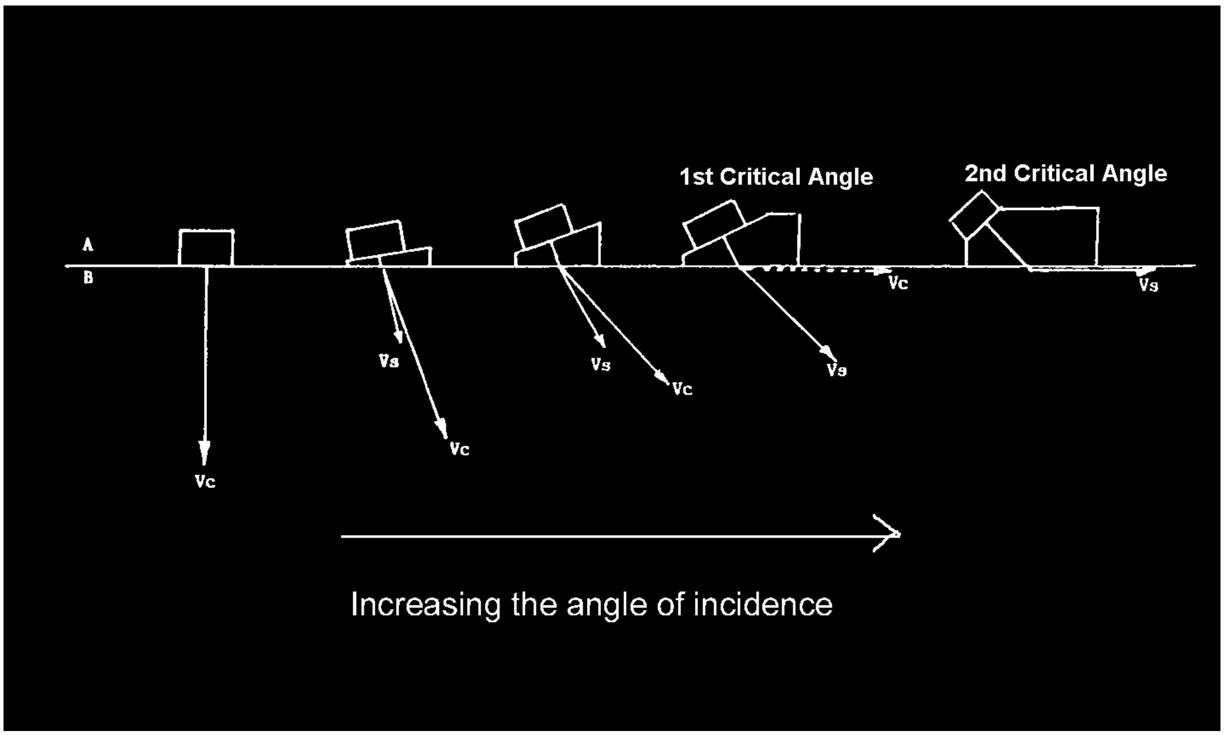


Figure 8-15 Increasing Incident Angle in Probe Shoes (Wedges) With Second Medium of Higher Velocity

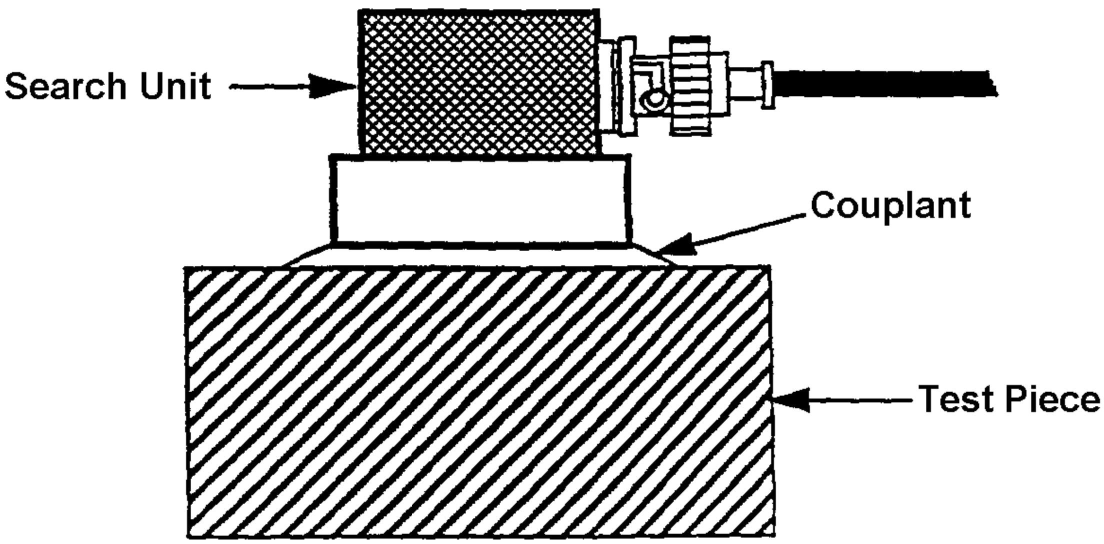


Figure 8-16 Transducer Coupled to Test Piece

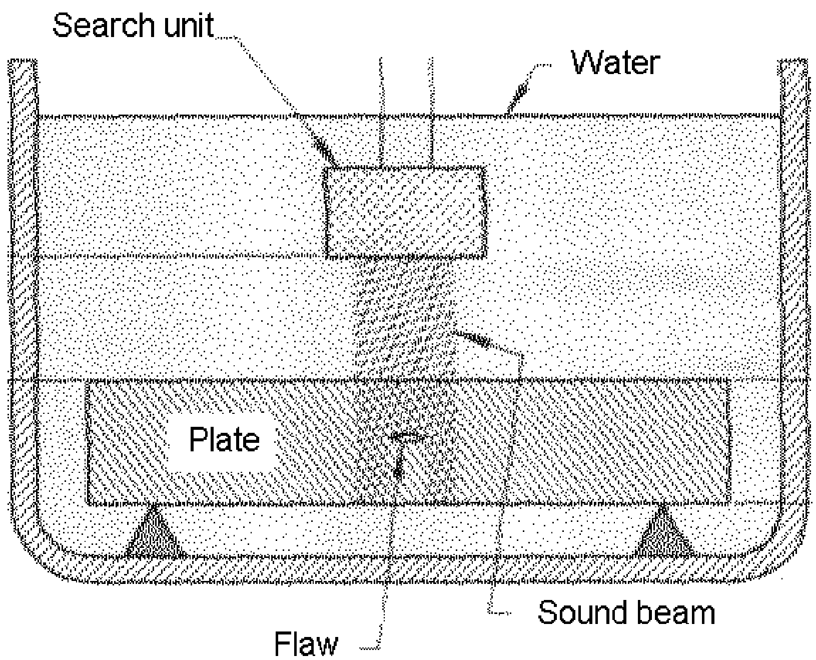


Figure 8-17 Immersion Test

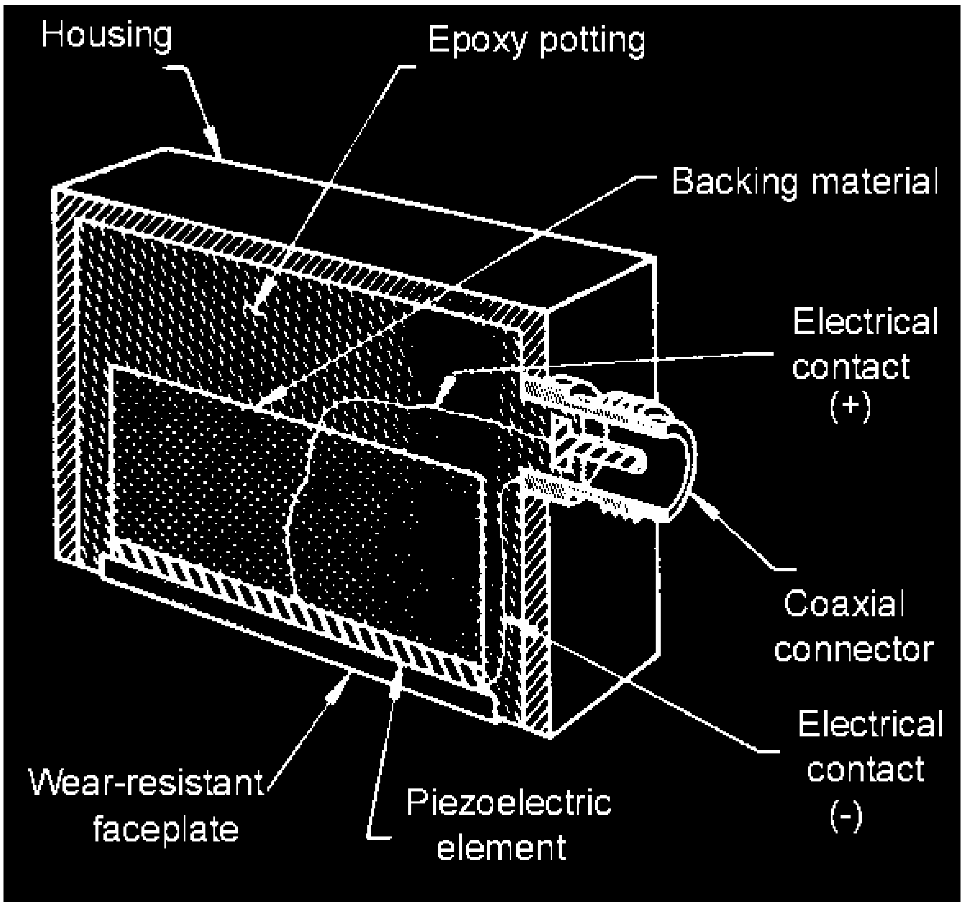


Figure 8-18 Normal Compressional Wave Probe

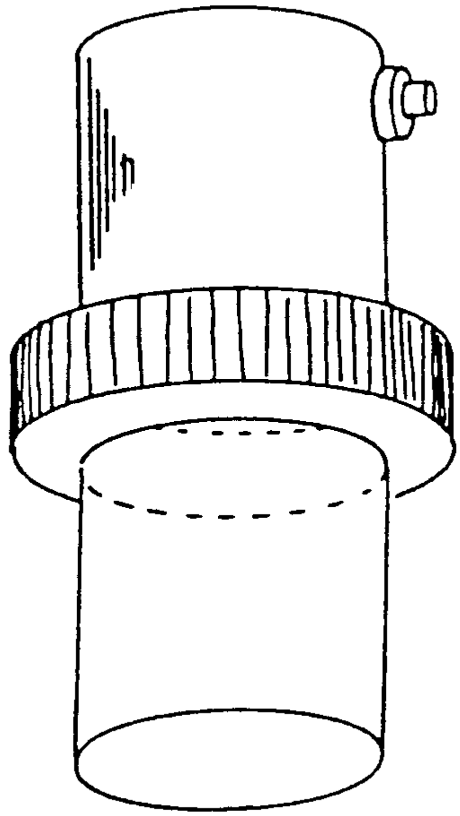


Figure 8-19 Delay Line Probe

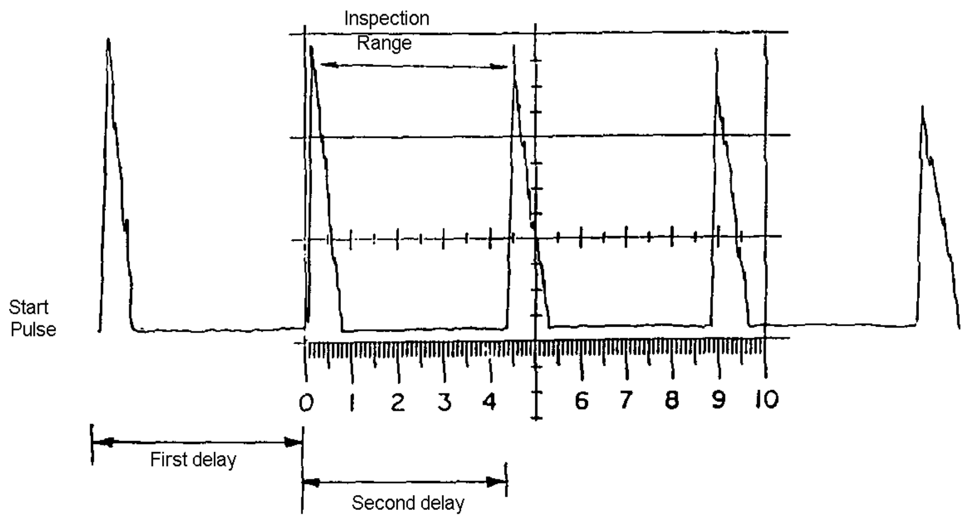


Figure 8-20 Calibration of Timebase for Delay Line Probe

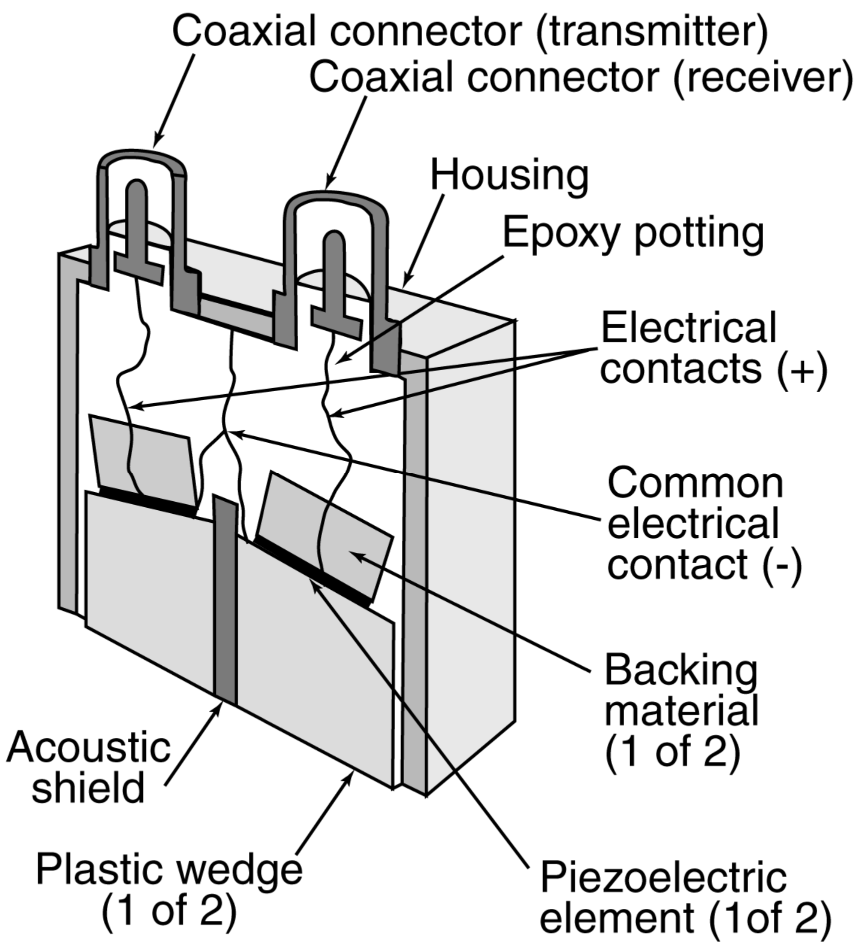


Figure 8-21 Dual Element Probe (Pitch-Catch)

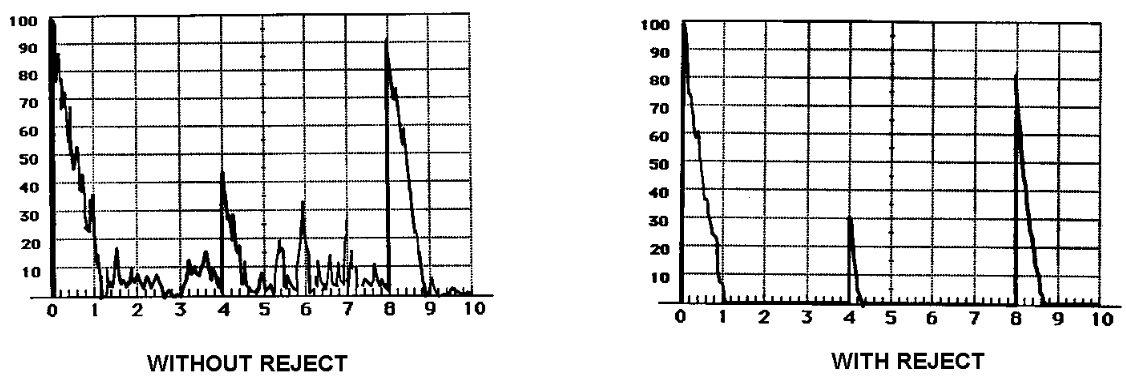


Figure 8-22 Use of Reject

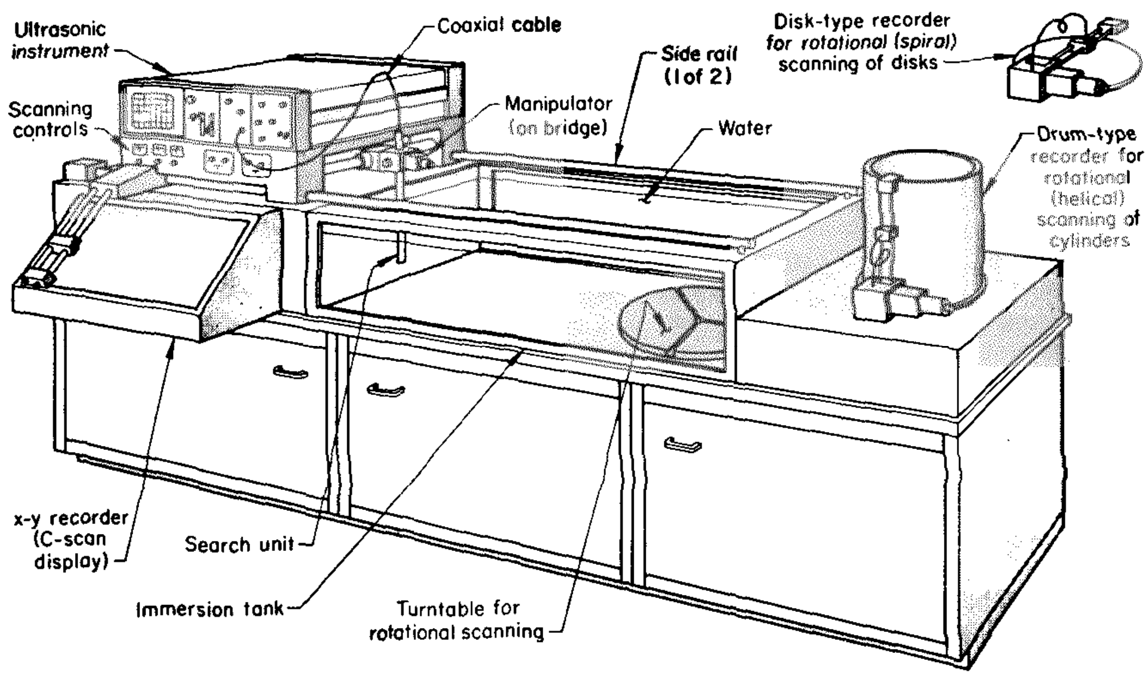


Figure 8-23 Typical Ultrasonic Tank and Bridge/Manipulator

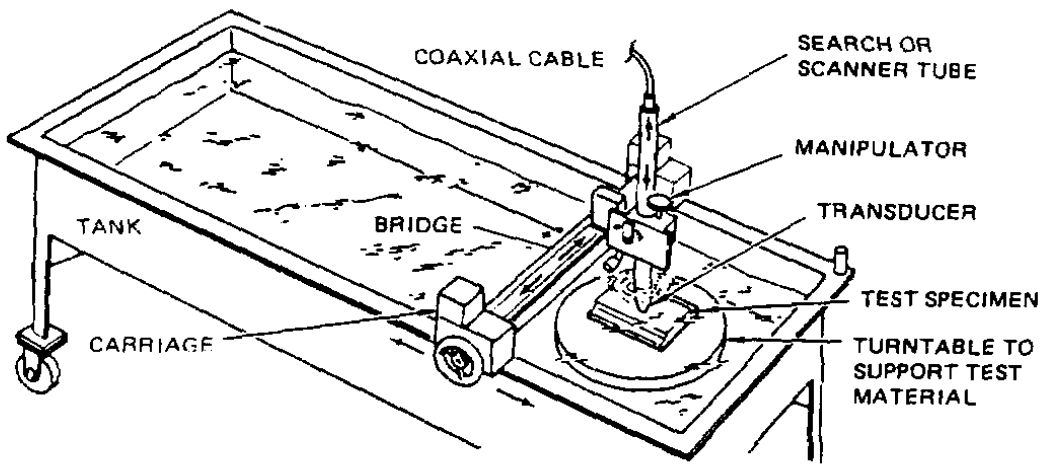


Figure 8-24 Bridge/Manipulator

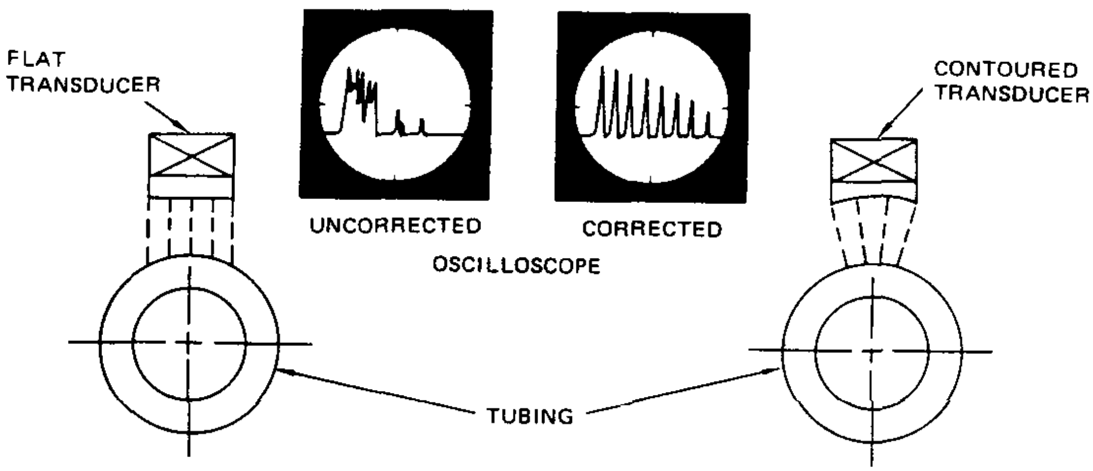


Figure 8-25 Flat and Contour-Corrected Transducers

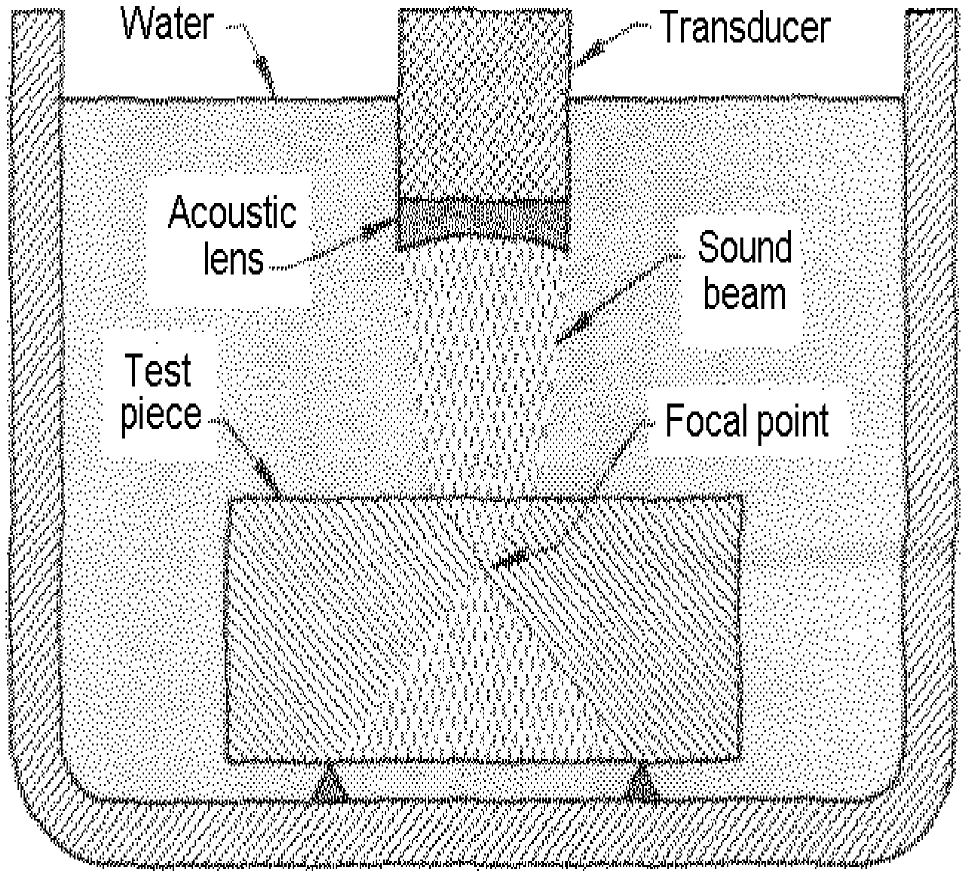


Figure 8-26 Focused-Beam Shortening in Metal

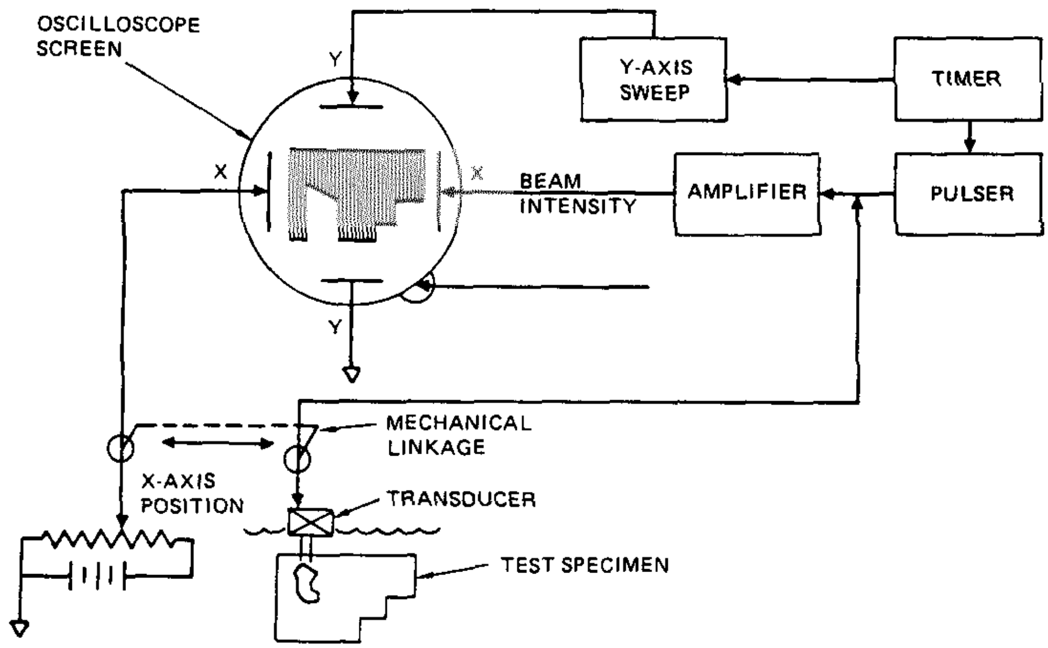


Figure 8-27 B-Scan Presentation

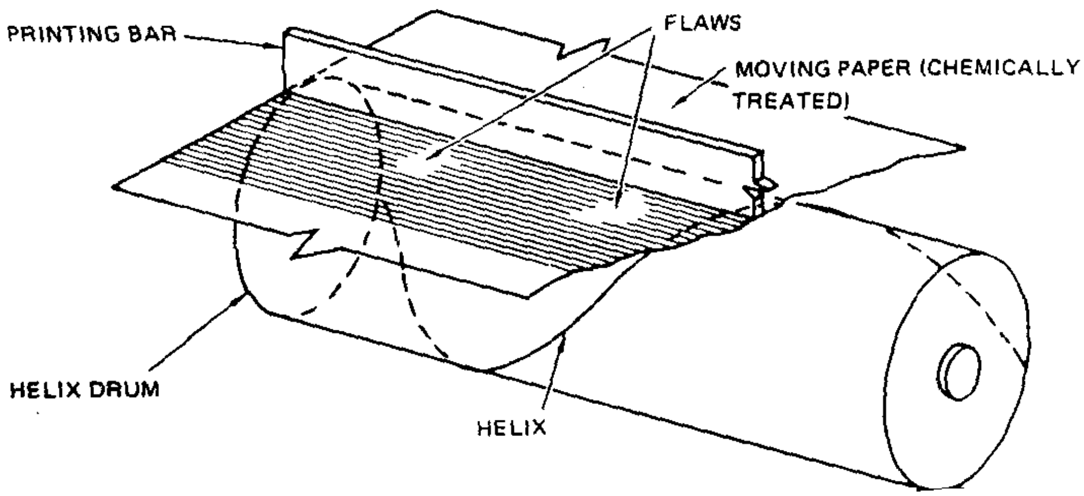


Figure 8-28 C-Scan Presentation

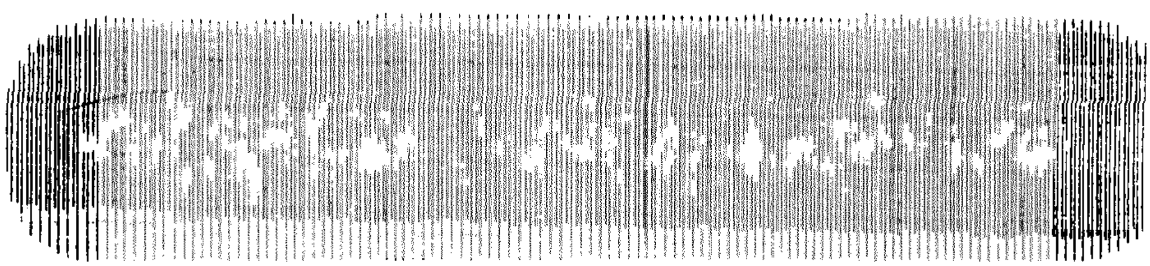


Figure 8-29 Typical C-Scan Recording

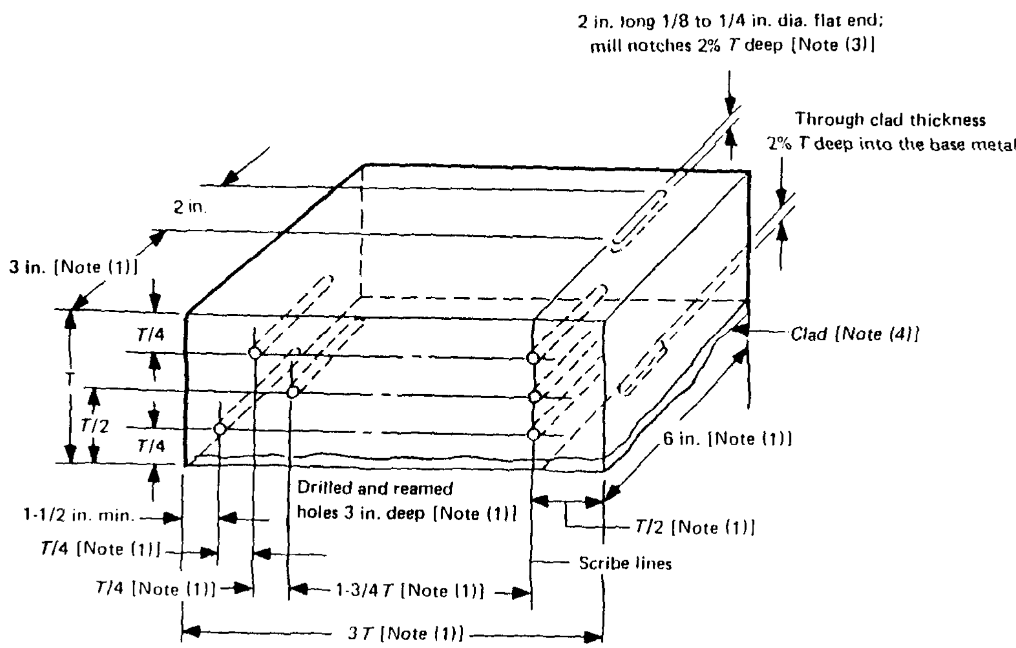


Figure 8-30 Basic Calibration Block

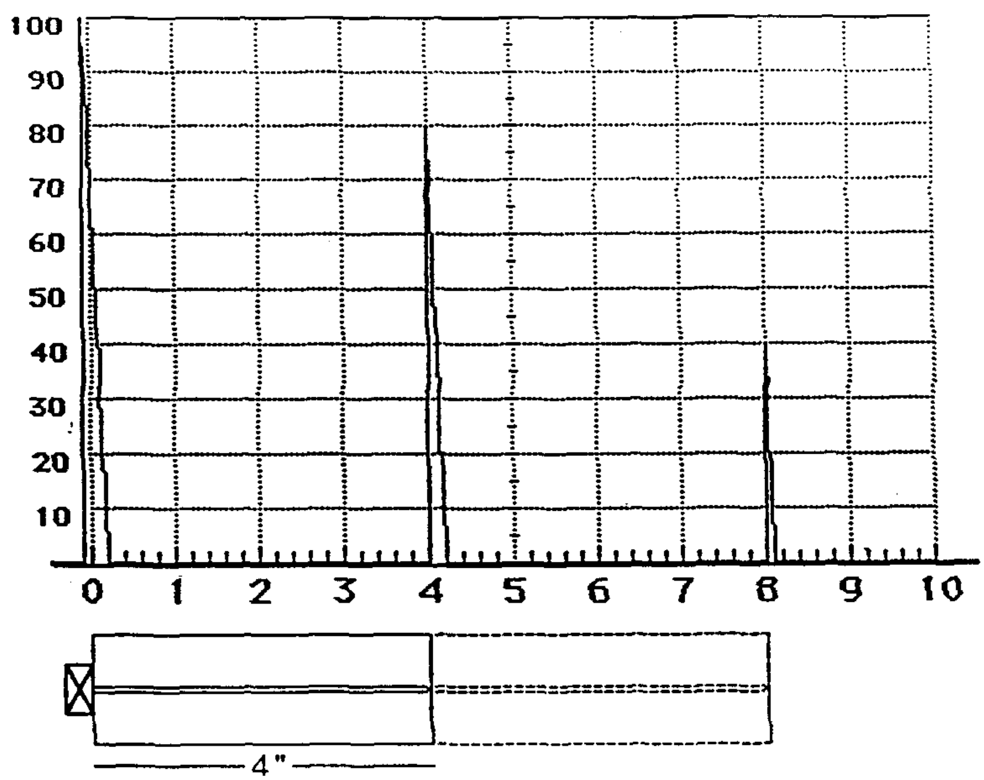


Figure 8-31 Distance Calibration

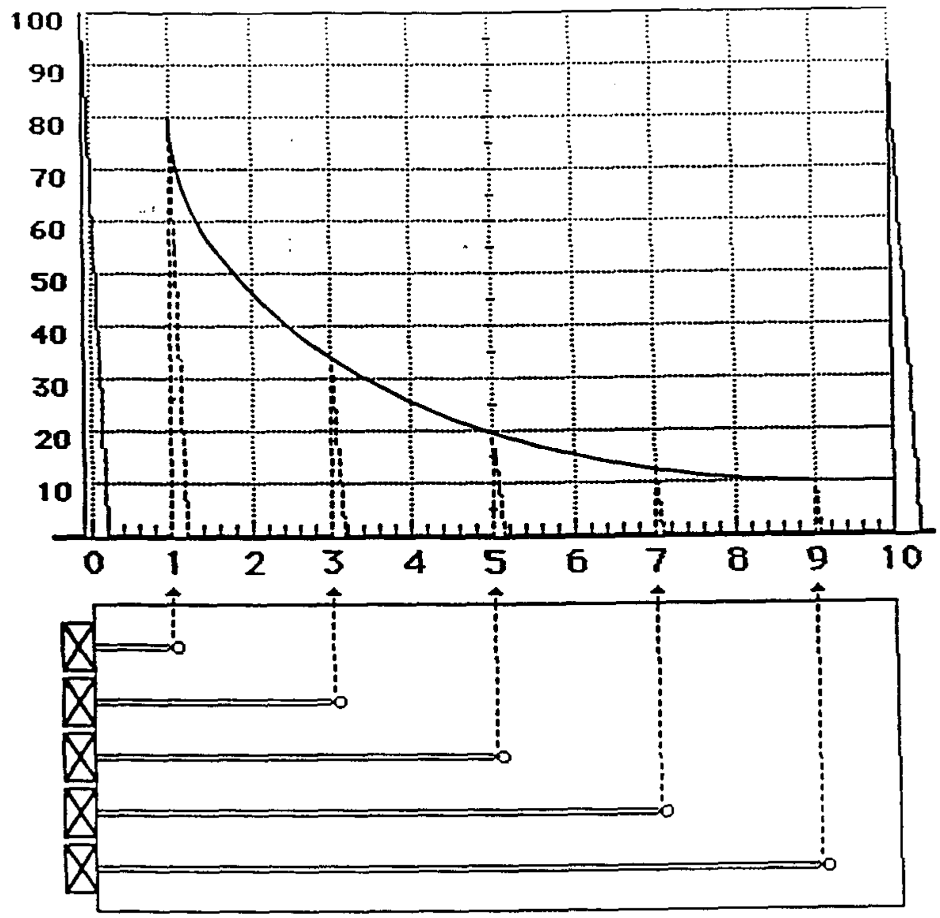


Figure 8-32 Distance Amplitude Calibration

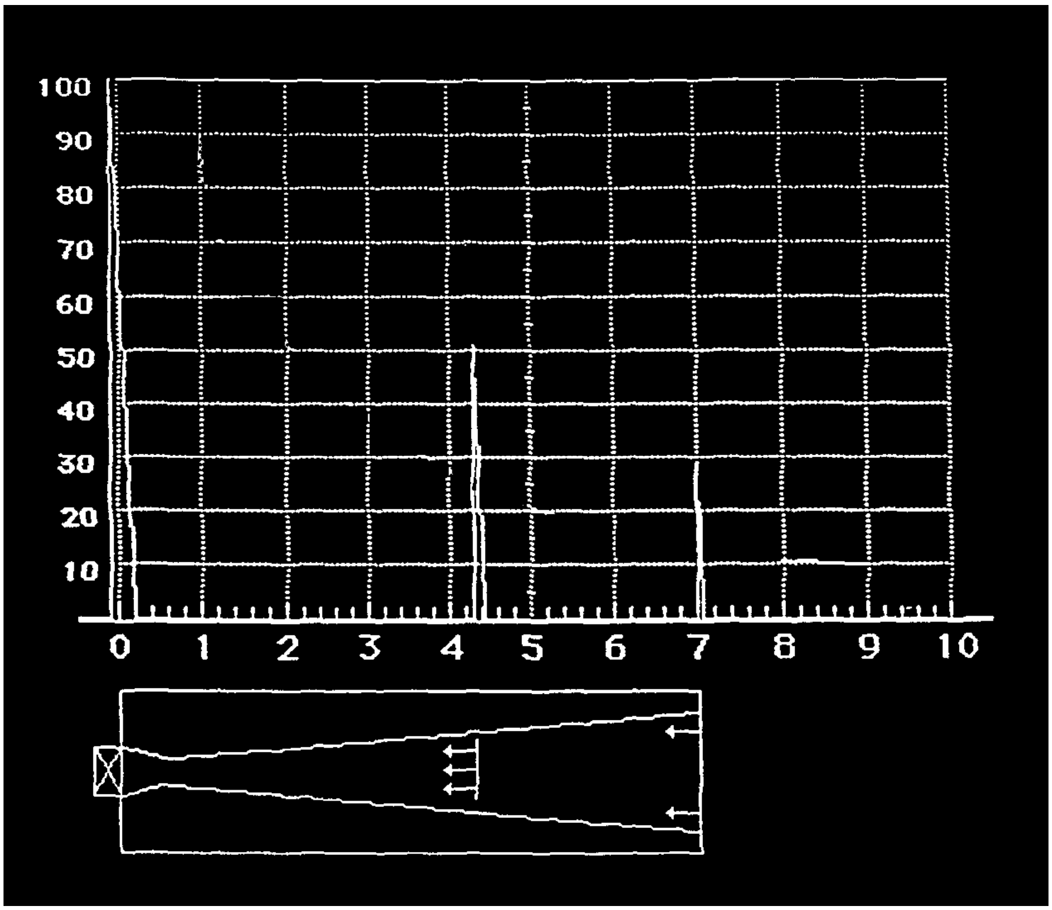


Figure 8-33 Linear Reflector

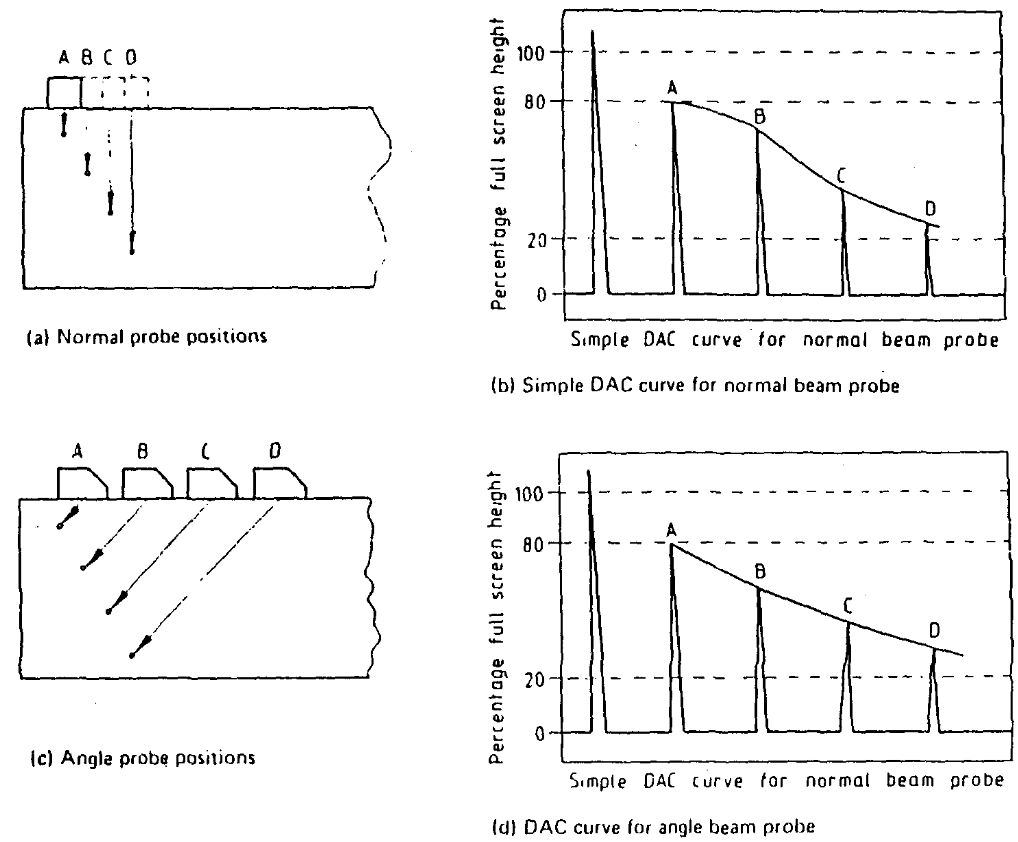


Figure 8-34 Distance Amplitude Correction Curves

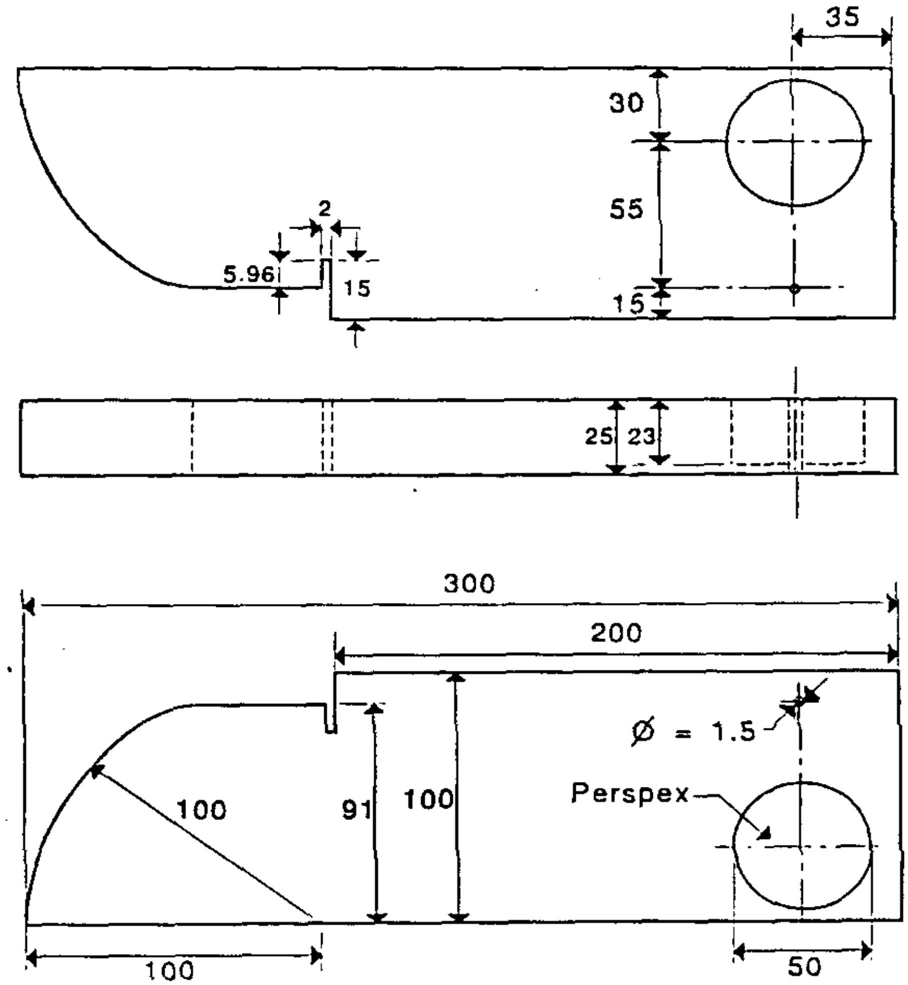


Figure 8-35 Block A2 (IIW Block)

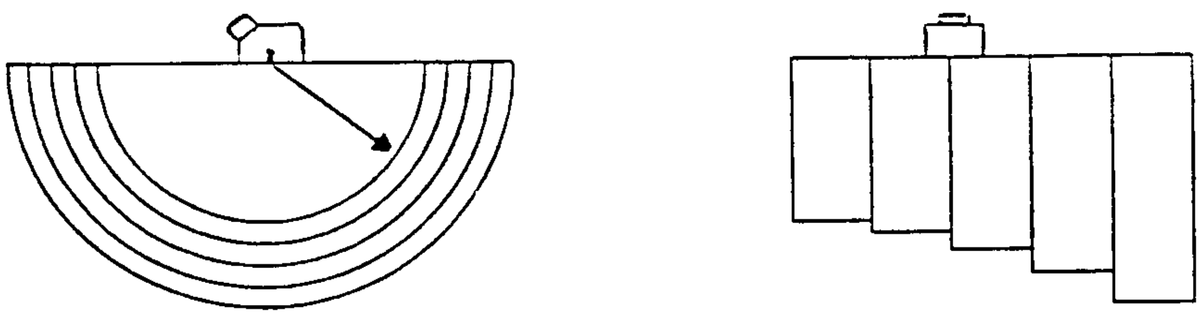


Figure 8-36 Block A7

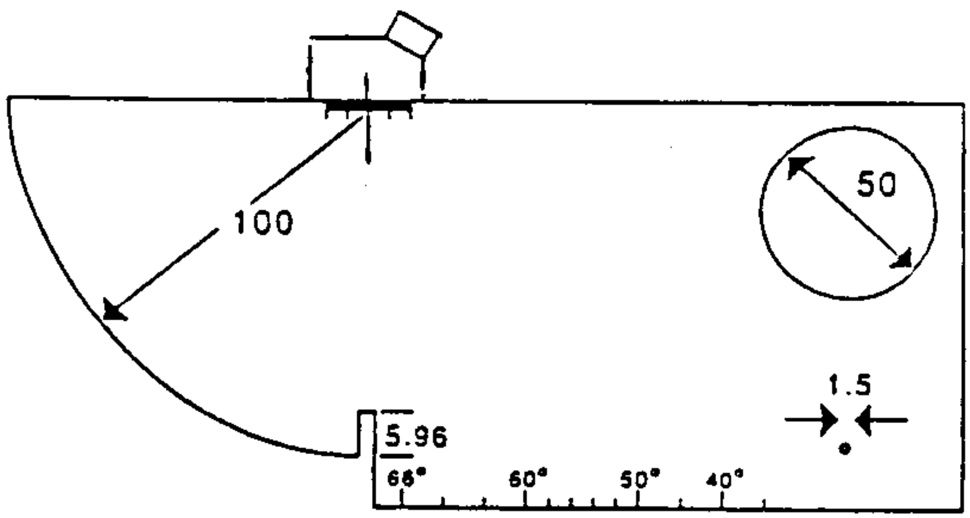
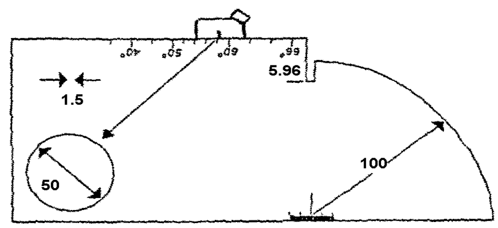
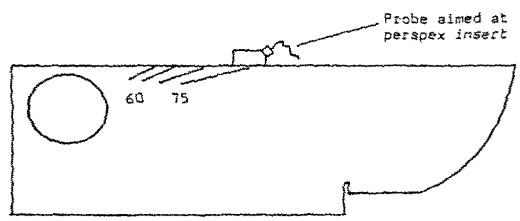


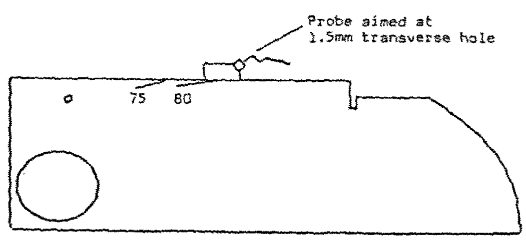
Figure 8-37 Checking Beam Index Point



A) CHECKING BEAM ANGLE 35 - 65 DEGREE PROBES



B) CHECKING BEAM ANGLE 60 - 75 DEGREE PROBES



C) CHECKING BEAM ANGLE 75 - 80 DEGREE PROBES

Figure 8-38 Checking Beam Angle

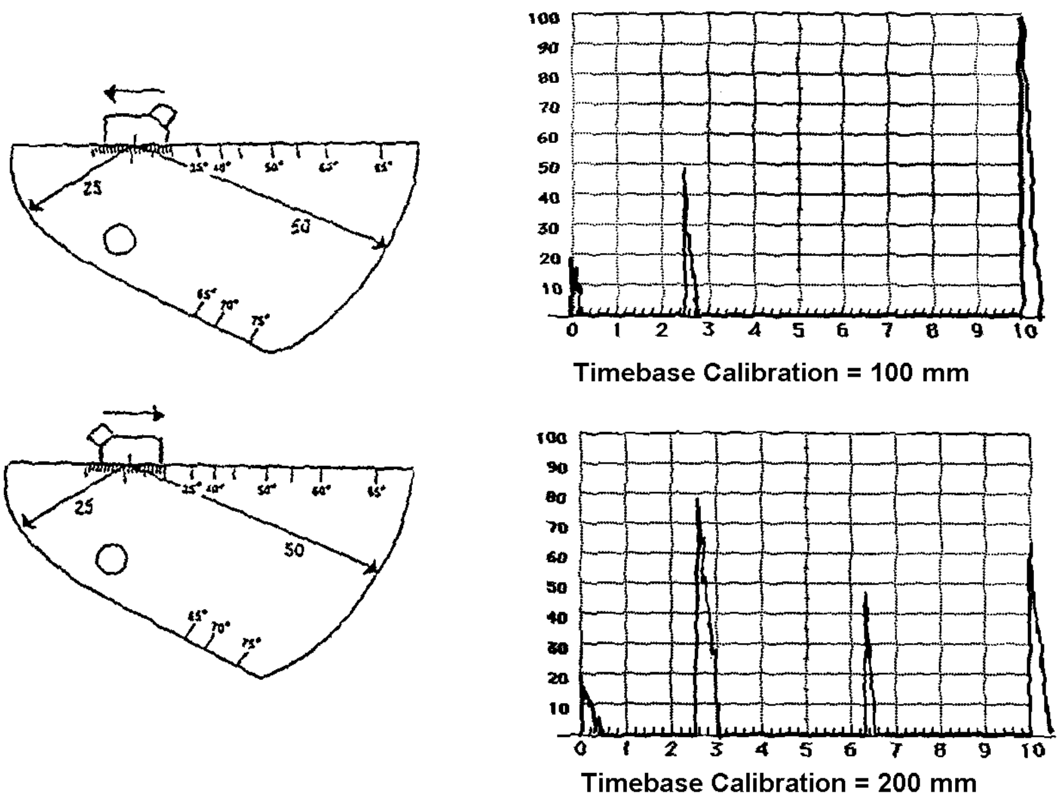


Figure 8-39 Timebase Calibration for Shear Wave Probe Using A4 Block

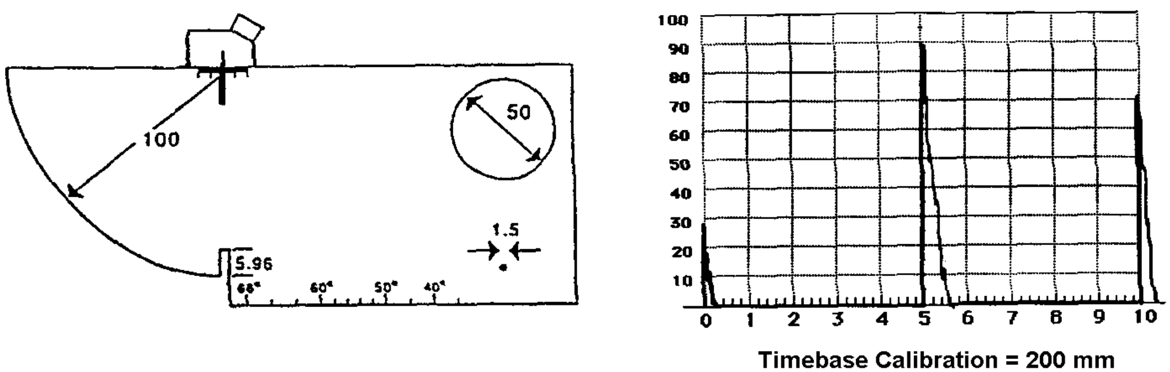


Figure 8-40 Time Base Calibration for Shear Wave Probe Using A2 Block Modified with Slots

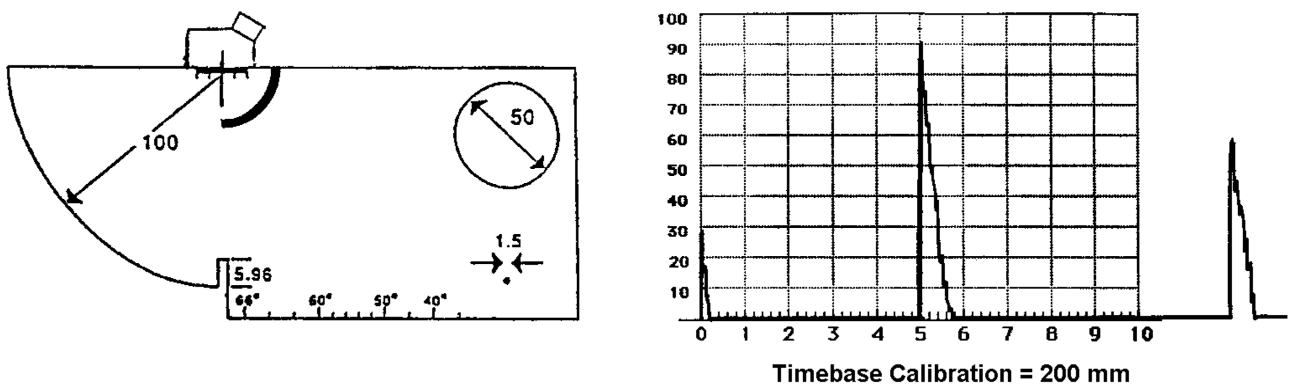


Figure 8-41 Time Base Calibration for Shear Wave Probe Using A2 Block Modified with 25mm Radius