ULTRASONIC TESTING

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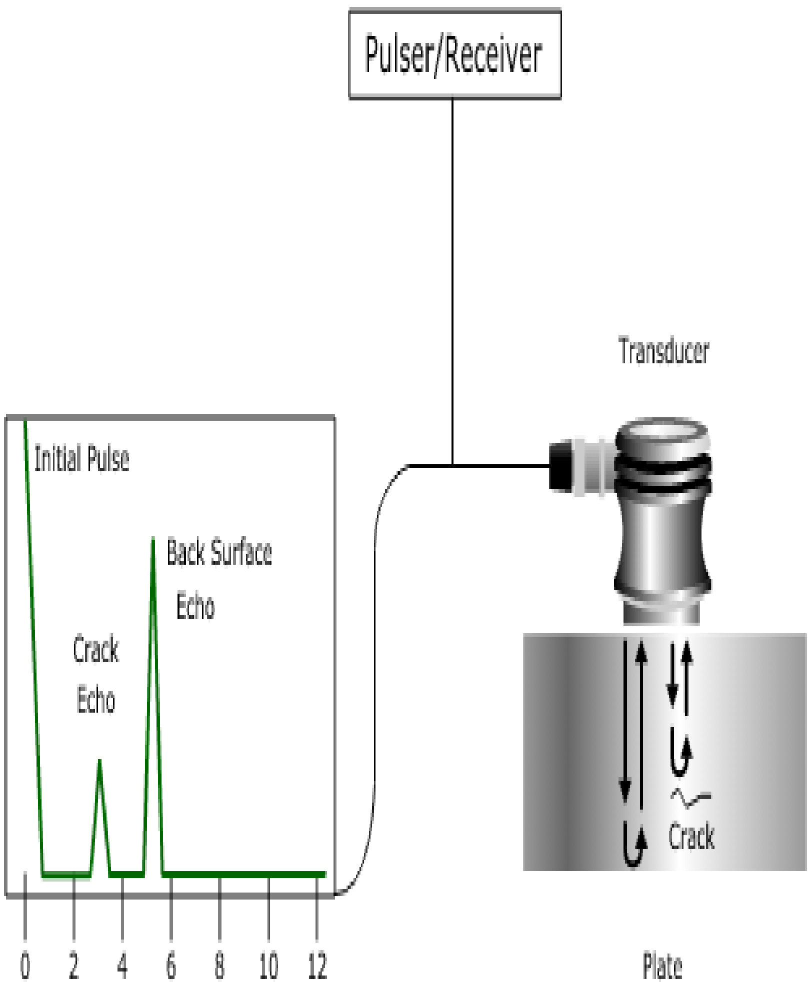
Basic Principles of Ultrasonic Testing

- Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more.



- A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices.
- A pulser/receiver is an electronic device that can produce high voltage electrical pulses.
- Driven by the pulser, the transducer generates high frequency ultrasonic energy.
- The sound energy is introduced and propagates through the materials in the form of waves.
- When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface.
- The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen.

Advantages

- It is sensitive to both surface and subsurface discontinuities.
- The depth of penetration for flaw detection or measurement is superior to other NDT methods.
- Only single-sided access is needed when the pulse-echo technique is used.
- It is highly accurate in determining reflector position and estimating size and shape.
- Minimal part preparation is required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- It has other uses, such as thickness measurement, in addition to flaw detection.

Limitations

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration and the characterization of flaws.

History of ultrasonics

- In 1929 and 1935, Sokolov studied the use of ultrasonic waves in detecting metal objects.
- Mulhauser, in 1931, obtained a patent for using ultrasonic waves, using two transducers to detect flaws in solids.
- Firestone (1940) and Simons (1945) developed pulsed ultrasonic testing using a pulse-echo technique.
- "damage tolerant" design, quantitative nondestructive evaluation (QNDE)

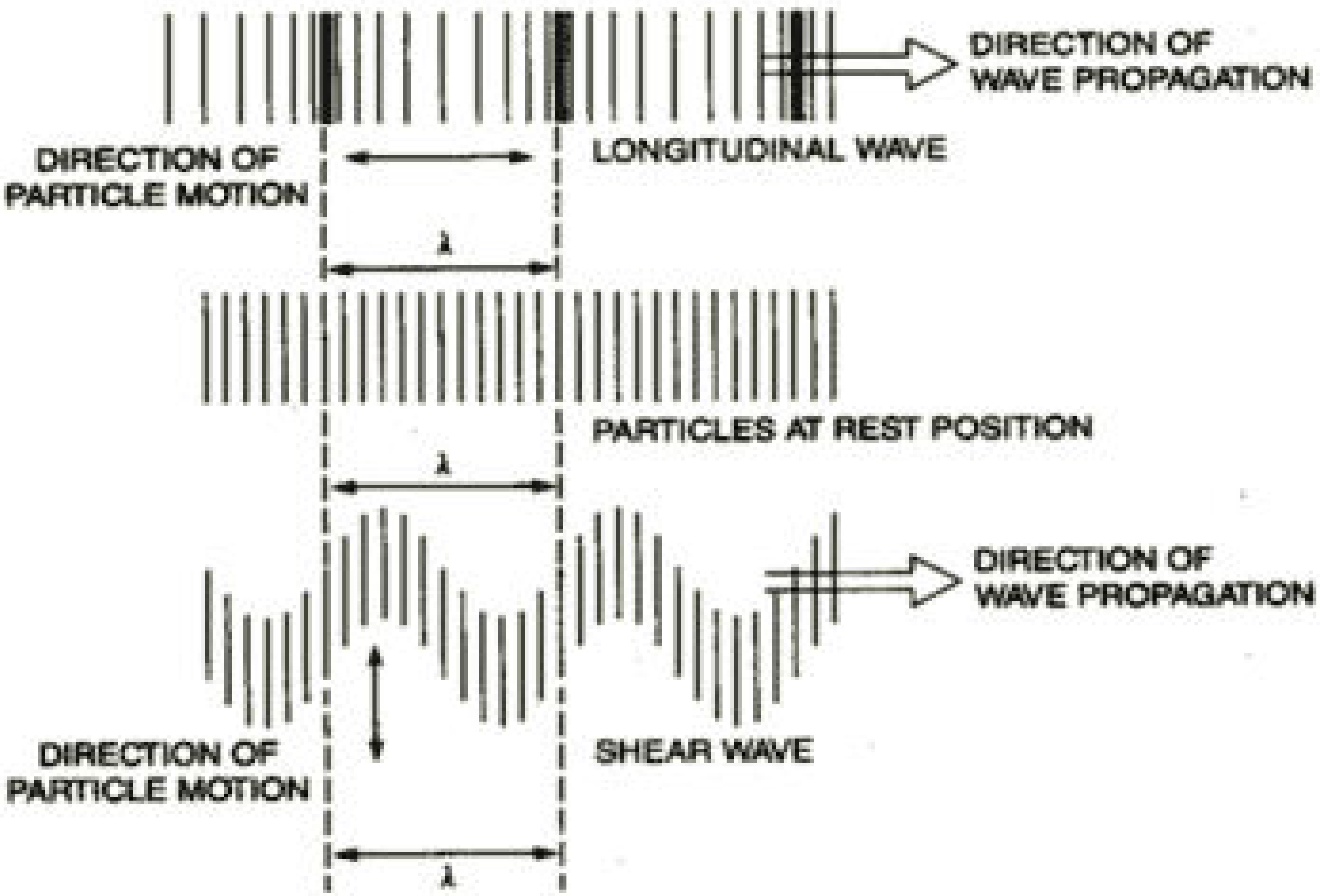
Physics of ultrasound

Introduction

- Ultrasonic testing is based on time-varying deformations or vibrations in materials, which is generally referred to as acoustics.
- All material substances are comprised of atoms, which may be forced into vibrational motion about their equilibrium positions.
- Many different patterns of vibrational motion exist at the atomic level, however, most are irrelevant to acoustics and ultrasonic testing.
- Acoustics is focused on particles that contain many atoms that move in unison to produce a mechanical wave.
- When a material is not stressed in tension or compression beyond its elastic limit, its individual particles perform elastic oscillations.
- When the particles of a medium are displaced from their equilibrium positions, internal (electrostatic) restoration forces arise. It is these elastic restoring forces between particles, combined with inertia of the particles, that leads to the oscillatory motions of the medium.

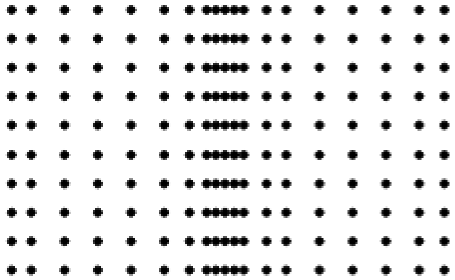
- In solids, sound waves can propagate in four principle modes that are based on the way the particles oscillate.
- Sound can propagate as longitudinal waves, shear waves, surface waves, and in thin materials as plate waves.
- Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing.
- The particle movement responsible for the propagation of longitudinal and shear waves

Wave propagation



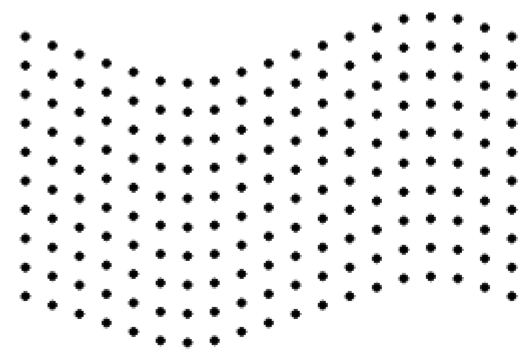
Longitudinal wave

- In longitudinal waves, the oscillations occur in the longitudinal direction or the direction of wave propagation.
- Since compressional and dilational forces are active in these waves, they are also called pressure or compressional waves.
- They are also sometimes called density waves because their particle density fluctuates as they move.
- Compression waves can be generated in liquids, as well as solids because the energy travels through the atomic structure by a series of compressions and expansion (rarefaction) movements.



Shear wave

- In the transverse or shear wave, the particles oscillate at a right angle or transverse to the direction of propagation.
- Shear waves require an acoustically solid material for effective propagation, and therefore, are not effectively propagated in materials such as liquids or gasses.
- Shear waves are relatively weak when compared to longitudinal waves.
- In fact, shear waves are usually generated in materials using some of the energy from longitudinal waves.



Modes of sound wave propagation

- At surfaces and interfaces, various types of elliptical or complex vibrations of the particles make other waves possible. Some of these wave modes such as Rayleigh and Lamb waves are also useful for ultrasonic inspection.

Wave Types in Solids	Particle Vibrations
Longitudinal	Parallel to wave direction
Transverse (Shear)	Perpendicular to wave direction
Surface - Rayleigh	Elliptical orbit - symmetrical mode
Plate Wave - Lamb	Component perpendicular to surface (extensional wave)
Plate Wave - Love	Parallel to plane layer, perpendicular to wave direction
Stoneley (Leaky Rayleigh Waves)	Wave guided along interface
Sezawa	Antisymmetric mode

Properties of acoustic waves

- he wavelength is directly proportional to the velocity of the wave and inversely proportional to the frequency of the wave.
- This relationship is shown by the following equation.

$$Wavelength(\lambda) = \frac{Velocity(v)}{Frequency(f)}$$

Wavelength and defect detection

- In ultrasonic testing, the inspector must make a decision about the frequency of the transducer that will be used.
- Changing the frequency when the sound velocity is fixed will result in a change in the wavelength of the sound.
- The wavelength of the ultrasound used has a significant effect on the probability of detecting a discontinuity.
- A general rule of thumb is that a discontinuity must be larger than one-half the wavelength to stand a reasonable chance of being detected.

Sensitivity and resolution

- Sensitivity and resolution are two terms that are often used in ultrasonic inspection to describe a technique's ability to locate flaws.
- Sensitivity is the ability to locate small discontinuities. Sensitivity generally increases with higher frequency (shorter wavelengths).
- Resolution is the ability of the system to locate discontinuities that are close together within the material or located near the part surface. Resolution also generally increases as the frequency increases.

What properties of material affect its speed of sound?

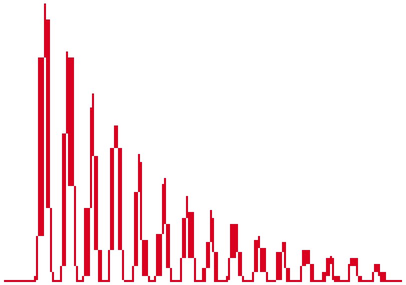
- Sound does travel at different speeds in different materials. This is because the mass of the atomic particles and the spring constants are different for different materials. The mass of the particles is related to the density of the material, and the spring constant is related to the elastic constants of a material. The general relationship between the speed of sound in a solid and its density and elastic constants is given by the following equation:

$$V = \sqrt{\frac{C_{ij}}{\rho}}$$

- Where **V** is the speed of sound, **C** is the elastic constant, and ***p*** is the material density. This equation may take a number of different forms depending on the type of wave (longitudinal or shear) and which of the elastic constants that are used. The typical elastic constants of a materials include:
  - Young's Modulus, **E**: a proportionality constant between uniaxial stress and strain.
  - Poisson's Ratio, **n**: the ratio of radial strain to axial strain
  - Bulk modulus, **K**: a measure of the incompressibility of a body subjected to hydrostatic pressure.
  - Shear Modulus, **G**: also called rigidity, a measure of a substance's resistance to shear.
  - Lame's Constants, **l** and **m**: material constants that are derived from Young's Modulus and Poisson's Ratio.

Attenuation of Sound Waves

•When sound travels through a medium, its intensity diminishes with distance. In idealized materials, sound pressure (signal amplitude) is only reduced by the spreading of the wave.
•Natural materials, however, all produce an effect which further weakens the sound. This further weakening results from scattering and absorption.
•Scattering is the reflection of the sound in directions other than its original direction of propagation.
•Absorption is the conversion of the sound energy to other forms of energy.
•The combined effect of scattering and absorption is called **attenuation**. Ultrasonic attenuation is the decay rate of the wave as it propagates through material.



$$A = A_0 e^{-\alpha z}$$

Acoustic Impedance

- Sound travels through materials under the influence of sound pressure. Because molecules or atoms of a solid are bound elastically to one another, the excess pressure results in a wave propagating through the solid.
- The **acoustic impedance** (**Z**) of a material is defined as the product of its density (**p**) and acoustic velocity (**V**)
- **Z = pV**
- Acoustic impedance is important in
  - the determination of acoustic transmission and reflection at the boundary of two materials having different acoustic impedances.
  - the design of ultrasonic transducers.
  - assessing absorption of sound in a medium.

Mode conversion

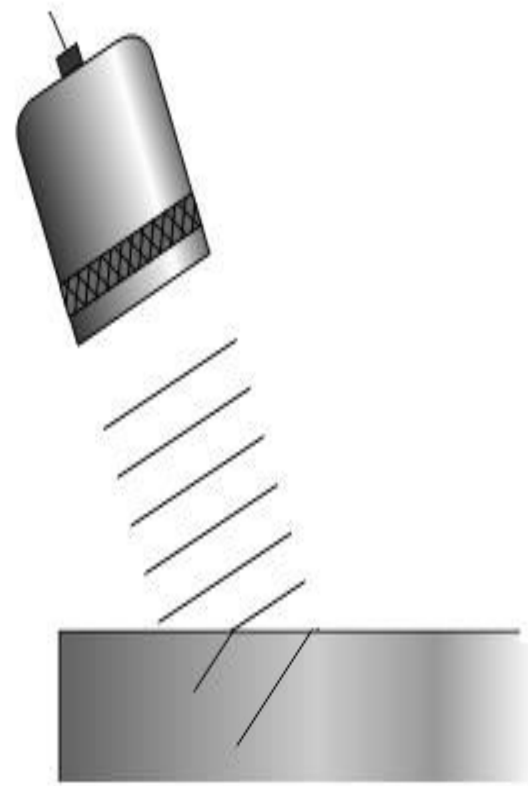
- When sound travels in a solid material, one form of wave energy can be transformed into another form.
- For example, when a longitudinal waves hits an interface at an angle, some of the energy can cause particle movement in the transverse direction to start a shear (transverse) wave.
- Mode conversion occurs when a wave encounters an interface between materials of different acoustic impedances and the incident angle is not normal to the interface.

Reflection and transmission coefficients

- Ultrasonic waves are reflected at boundaries where there is a difference in acoustic impedances (Z) of the materials on each side of the boundary.
- This difference in Z is commonly referred to as the impedance mismatch. The greater the impedance mismatch, the greater the percentage of energy that will be reflected at the interface or boundary between one medium and another.

Refraction and Snell's Law

- Refraction takes place at an interface due to the different velocities of the acoustic waves within the two materials. The velocity of sound in each material is determined by the material properties (elastic modulus and density) for that material.

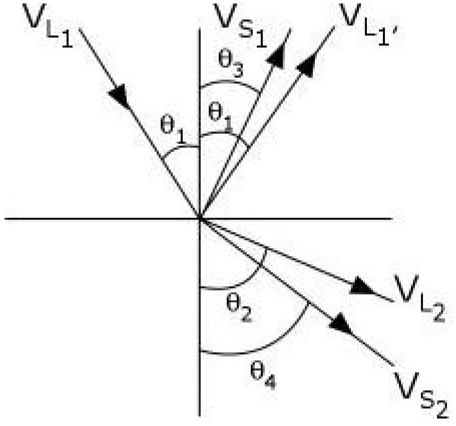


- Snell's Law describes the relationship between the angles and the velocities of the waves.
- Snell's law equates the ratio of material velocities **V_1** and **V_2** to the ratio of the **sine's** of incident (**Q_1**) and refracted (**Q_2**) angles, as shown in the following equation.

$$\frac{\sin\theta_1}{V_{L_1}} = \frac{\sin\theta_2}{V_{L_2}}$$

Where:
V_{L1} is the longitudinal wave velocity in material 1.
V_{L2} is the longitudinal wave velocity in material 2.

- Snell's Law holds true for shear waves as well as longitudinal waves and can be written as follows.



$$\frac{\sin\theta_1}{V_{L_1}} = \frac{\sin\theta_2}{V_{L_2}} = \frac{\sin\theta_3}{V_{S_1}} = \frac{\sin\theta_4}{V_{S_2}}$$

Signal-to-Noise Ratio

- The absolute noise level and the absolute strength of an echo from a "small" defect depends on a number of factors, which include:
  - The probe size and focal properties.
  - The probe frequency, bandwidth and efficiency.
  - The inspection path and distance (water and/or solid).
  - The interface (surface curvature and roughness).
  - The flaw location with respect to the incident beam.
  - The inherent noisiness of the metal microstructure.
  - The inherent reflectivity of the flaw, which is dependent on its acoustic impedance, size, shape, and orientation.
  - Cracks and volumetric defects can reflect ultrasonic waves quite differently. Many cracks are "invisible" from one direction and strong reflectors from another.
  - Multifaceted flaws will tend to scatter sound away from the transducer.

Flaw scat. ampl. at center frequency

$$\frac{S}{N} = \sqrt{\frac{16}{\rho\, v_{metal}\, w_x\, w_y\, \Delta t}}\; \frac{A_{flaw}(f_0)}{FOM(f_0)}$$

sound speed in metal

lateral beam widths at flaw depth

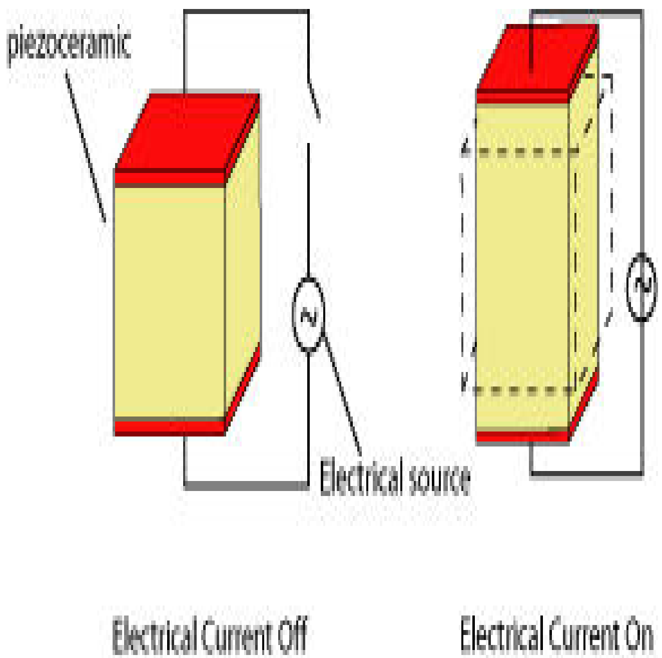
pulse duration

Noise FOM at center frequency

- The signal-to-noise ratio (S/N), and therefore, the detectability of a defect:
- Increases with increasing flaw size (scattering amplitude). The detectability of a defect is directly proportional to its size.
- Increases with a more focused beam. In other words, flaw detectability is inversely proportional to the transducer beam width.
- Increases with decreasing pulse width (delta-t). In other words, flaw detectability is inversely proportional to the duration of the pulse produced by an ultrasonic transducer. The shorter the pulse (often higher frequency), the better the detection of the defect. Shorter pulses correspond to broader bandwidth frequency response. See the figure below showing the waveform of a transducer and its corresponding frequency spectrum.
- Decreases in materials with high density and/or a high ultrasonic velocity. The signal-to-noise ratio (S/N) is inversely proportional to material density and acoustic velocity.
- Generally increases with frequency. However, in some materials, such as titanium alloys, both the "A_{flaw}" and the "Figure of Merit (FOM)" terms in the equation change at about the same rate with changing frequency. So, in some cases, the signal-to-noise ratio (S/N) can be somewhat independent of frequency.

- Equipment and transducers

Piezoelectric Transducers



- The conversion of electrical pulses to mechanical vibrations and the conversion of returned mechanical vibrations back into electrical energy is the basis for ultrasonic testing.
- The active element is the heart of the transducer as it converts the electrical energy to acoustic energy, and vice versa.
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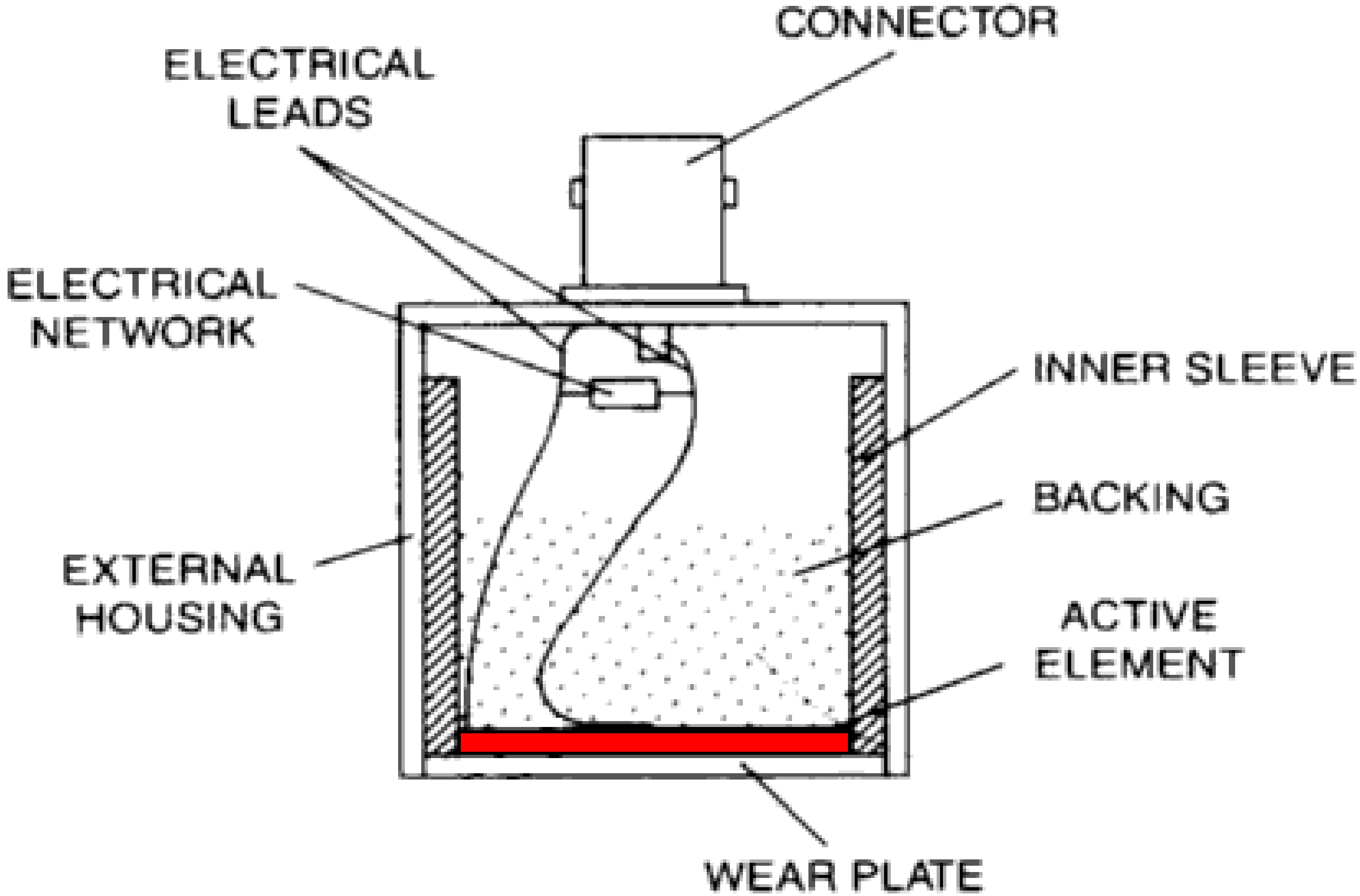
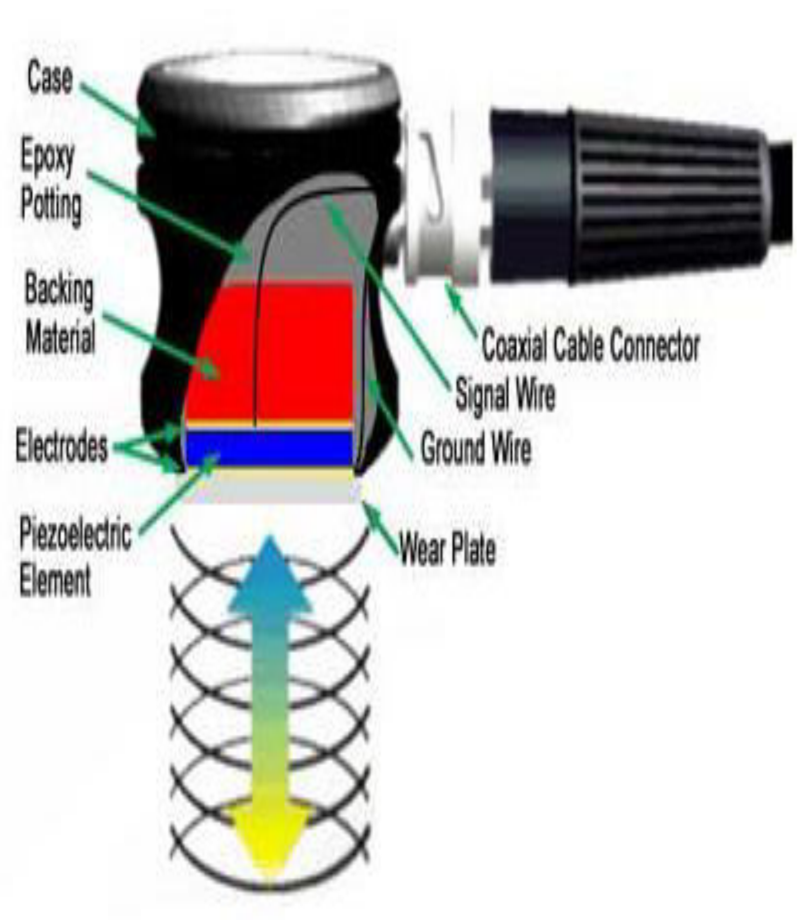

CONNECTOR
ELECTRICAL
LEADS
ELECTRICAL
NETWORK
INNER SLEEVE
BACKING
EXTERNAL
HOUSING
ACTIVE
ELEMENT
WEAR PLATE

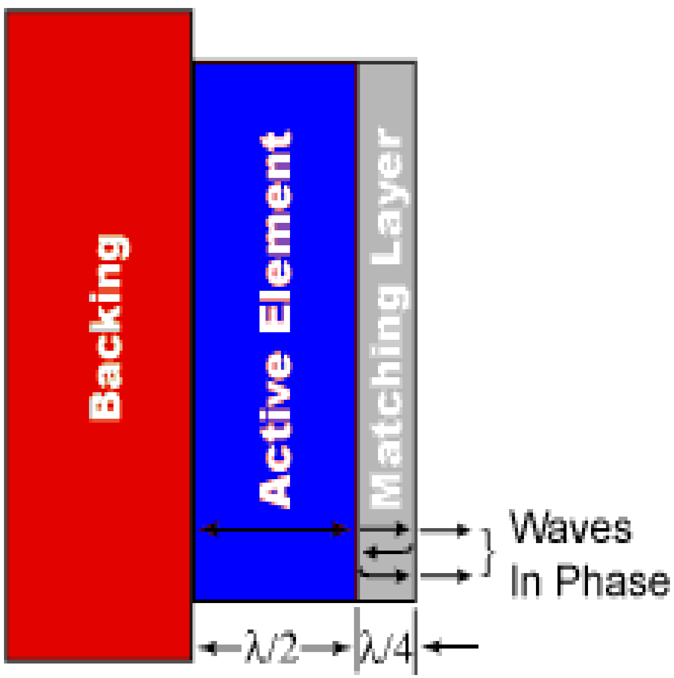
- The active element is basically a piece of polarized material (i.e. some parts of the molecule are positively charged, while other parts of the molecule are negatively charged) with electrodes attached to two of its opposite faces.
- When an electric field is applied across the material, the polarized molecules will align themselves with the electric field, resulting in induced dipoles within the molecular or crystal structure of the material.
- This alignment of molecules will cause the material to change dimensions.
- This phenomenon is known as electrostriction. In addition, a permanently-polarized material such as quartz (SiO_2) or barium titanate ($BaTiO_3$) will produce an electric field when the material changes dimensions as a result of an imposed mechanical force.
- This phenomenon is known as the piezoelectric effect.

- The thickness of the active element is determined by the desired frequency of the transducer. A thin wafer element vibrates with a wavelength that is twice its thickness.
- Therefore, piezoelectric crystals are cut to a thickness that is 1/2 the desired radiated wavelength. The higher the frequency of the transducer, the thinner the active element.
- The primary reason that high frequency contact transducers are not produced is because the element is very thin and too fragile.

Characteristics of Piezoelectric Transducers



- Many factors, including material, mechanical and electrical construction, and the external mechanical and electrical load conditions, influence the behavior of a transducer.
- Mechanical construction includes parameters such as the radiation surface area, mechanical damping, housing, connector type and other variables of physical construction.



- A cut away of a typical contact transducer is shown above. It was previously learned that the piezoelectric element is cut to 1/2 the desired wavelength.
- To get as much energy out of the transducer as possible, an impedance matching is placed between the active element and the face of the transducer.
- Optimal impedance matching is achieved by sizing the matching layer so that its thickness is 1/4 of the desired wavelength. This keeps waves that were reflected within the matching layer in phase when they exit the layer (as illustrated in the image to the right).
- For contact transducers, the matching layer is made from a material that has an acoustical impedance between the active element and steel. Immersion transducers have a matching layer with an acoustical impedance between the active element and water. Contact transducers also incorporate a wear plate to protect the matching layer and active element from scratching.

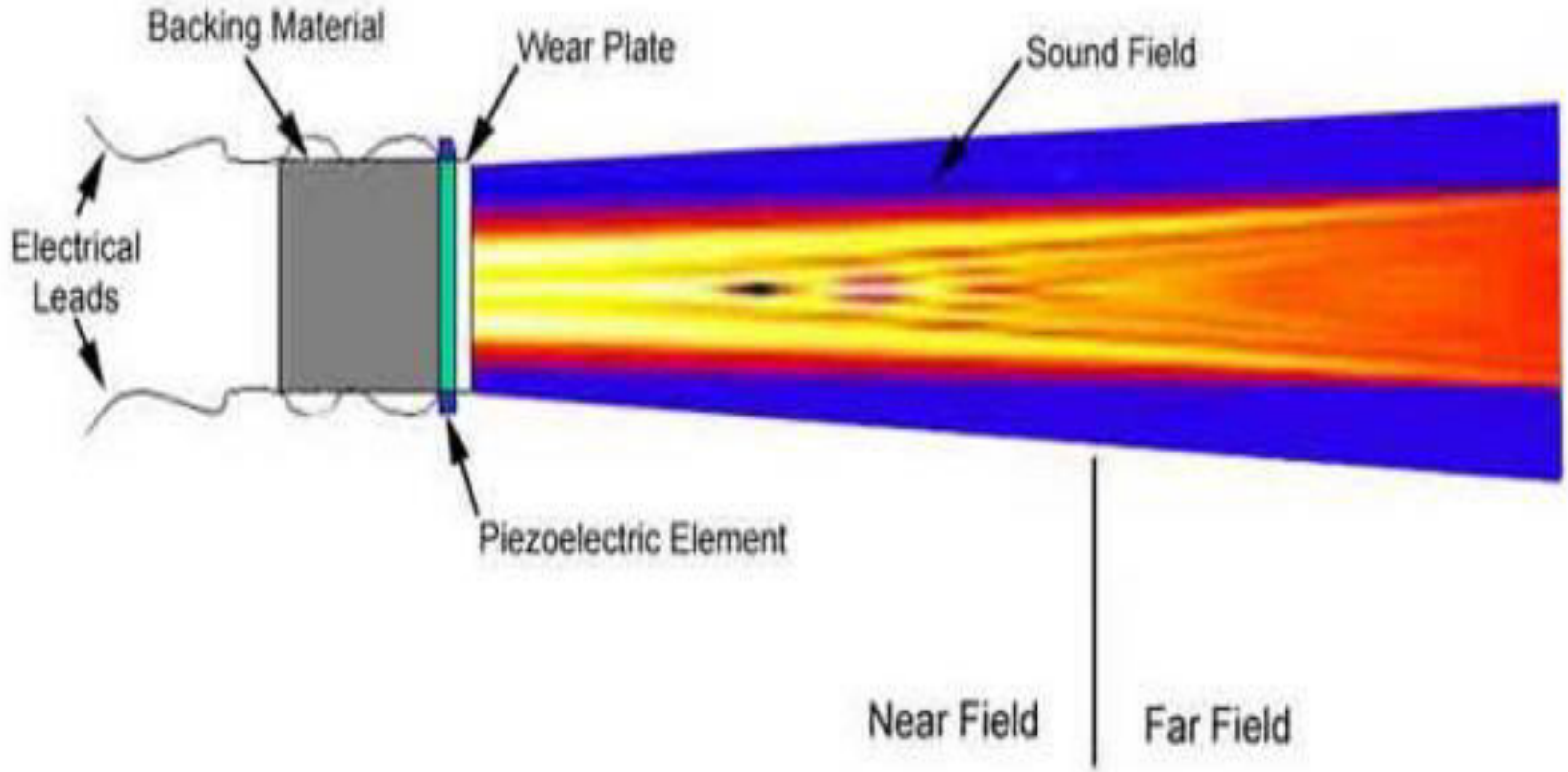
- The backing material supporting the crystal has a great influence on the damping characteristics of a transducer.
- Using a backing material with an impedance similar to that of the active element will produce the most effective damping. Such a transducer will have a wider bandwidth resulting in higher sensitivity.
- As the mismatch in impedance between the active element and the backing material increases, material penetration increases but transducer sensitivity is reduced.

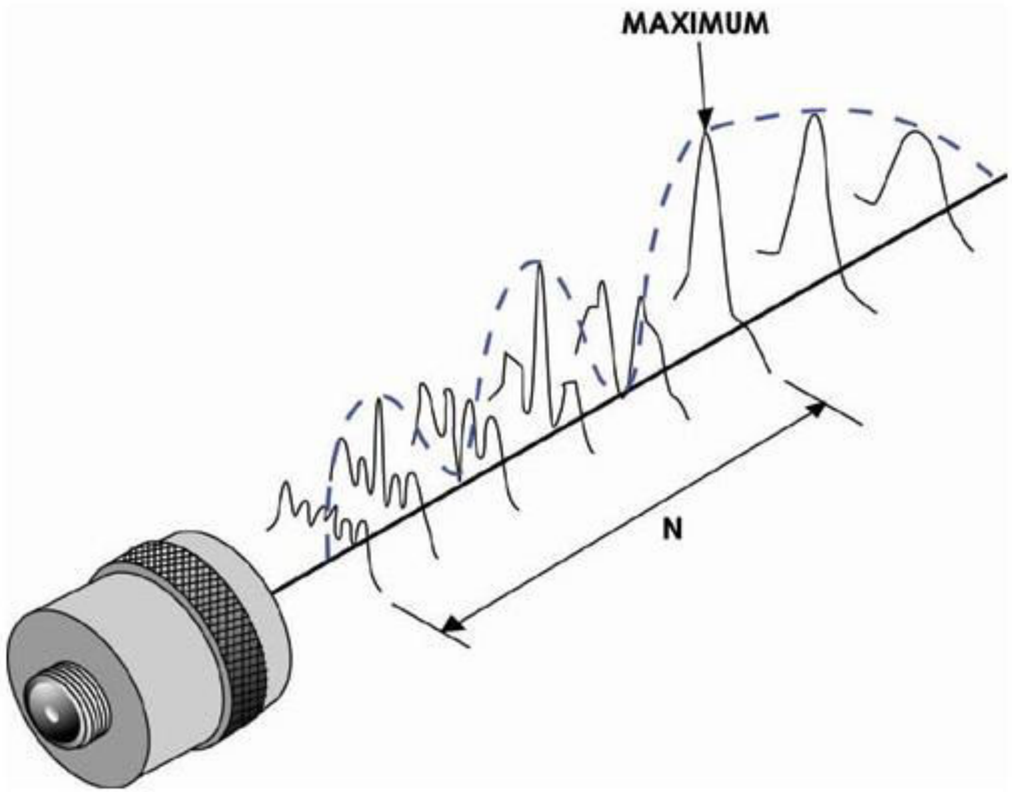
Transducer Efficiency, Bandwidth and Frequency

- A transducer that performs well in one application will not always produce the desired results in a different application.
- For example, sensitivity to small defects is proportional to the product of the efficiency of the transducer as a transmitter and a receiver.
- Resolution, the ability to locate defects near the surface or in close proximity in the material, requires a highly damped transducer.

- The frequency noted on a transducer is the central or center frequency and depends primarily on the backing material.
- Highly damped transducers will respond to frequencies above and below the central frequency.
- The broad frequency range provides a transducer with high resolving power.
- Less damped transducers will exhibit a narrower frequency range and poorer resolving power, but greater penetration.
- The central frequency will also define the capabilities of a transducer.
- Lower frequencies (0.5MHz-2.25MHz) provide greater energy and penetration in a material, while high frequency crystals (15.0MHz-25.0MHz) provide reduced penetration but greater sensitivity to small discontinuities.
- High frequency transducers, when used with the proper instrumentation, can improve flaw resolution and thickness measurement capabilities dramatically.
- Broadband transducers with frequencies up to 150 MHz are commercially available.

Radiated Fields of Ultrasonic Transducers




MAXIMUM
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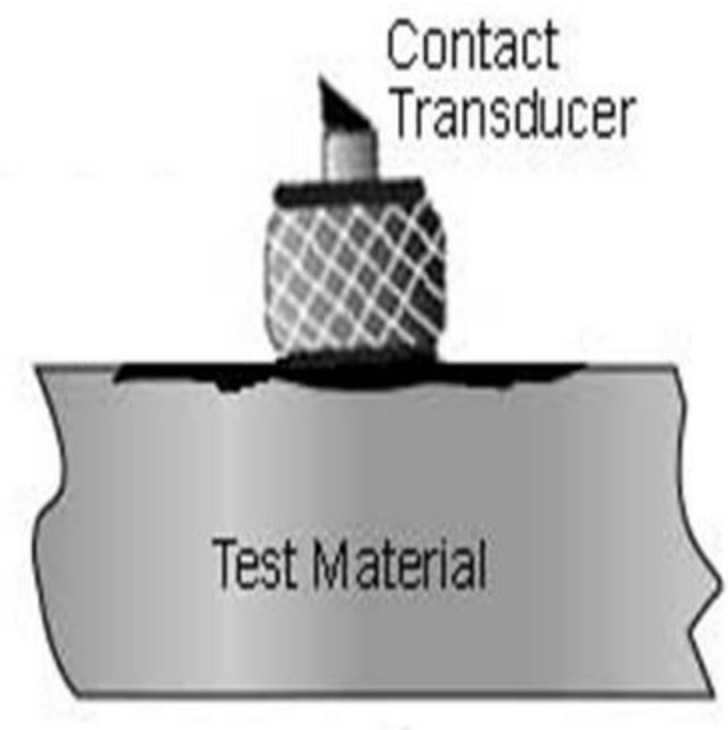
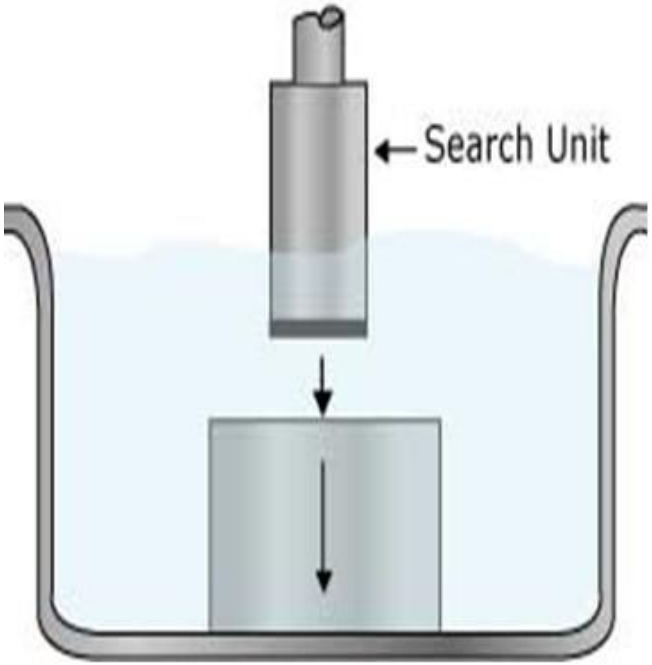
Transducer Types- Contact transducers

- **Contact transducers** are used for direct contact inspections, and are generally hand manipulated.
- They have elements protected in a rugge casing to withstand sliding contact with variety of materials.
- These transducers have an ergonomic desig so that they are easy to grip and move alon a surface.
- They often have replaceable wear plates t lengthen their useful life.
- Coupling materials of water, grease, oils, c commercial materials are used to remov the air gap between the transducer and th component being inspected.

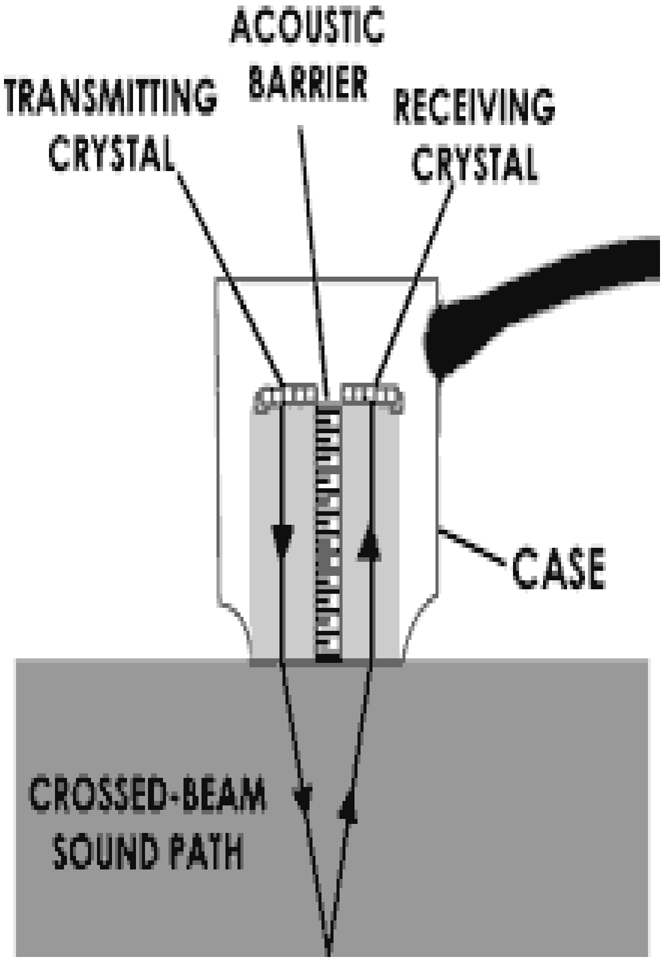


Immersion transducers

- **Immersion transducers** do not contact the component. These transducers are designed to operate in a liquid environment and all connections are watertight.
- Immersion transducers usually have an impedance matching layer that helps to get more sound energy into the water and, in turn, into the component being inspected. Immersion transducers can be purchased with a planer, cylindrically focused or spherically focused lens.
- A focused transducer can improve the sensitivity and axial resolution by concentrating the sound energy to a smaller area. Immersion transducers are typically used inside a water tank or as part of a squirter or bubbler system in scanning applications.



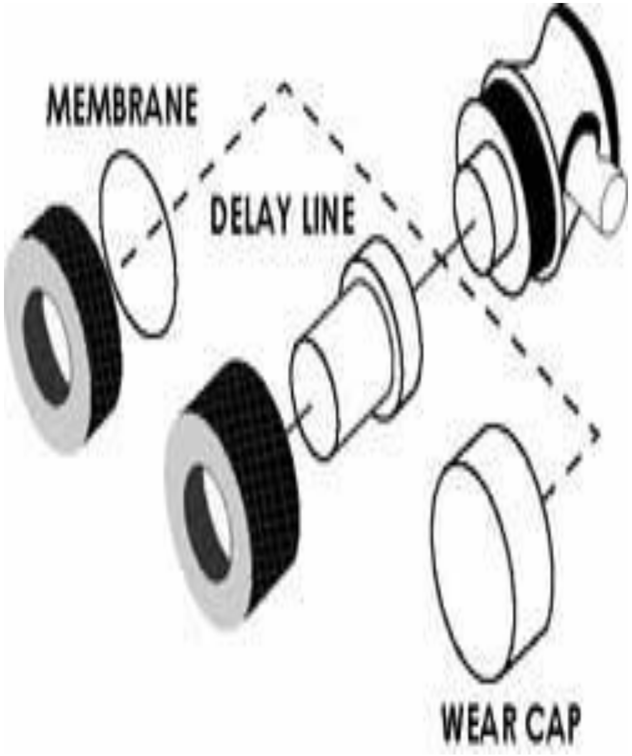
Dual element transducer



- **Dual element transducers** contain two independently operated elements in a single housing.
- One of the elements transmits and the other receives the ultrasonic signal.
- Active elements can be chosen for their sending and receiving capabilities to provide a transducer with a cleaner signal, and transducers for special applications, such as the inspection of course grained material.
- Dual element transducers are especially well suited for making measurements in applications where reflectors are very near the transducer since this design eliminates the ring down effect that single-element transducers experience (when single-element transducers are operating in pulse echo mode, the element cannot start receiving reflected signals until the element has stopped ringing from its transmit function).
- Dual element transducers are very useful when making thickness measurements of thin materials and when inspecting for near surface defects.
- The two elements are angled towards each other to create a crossed-beam sound path in the test material

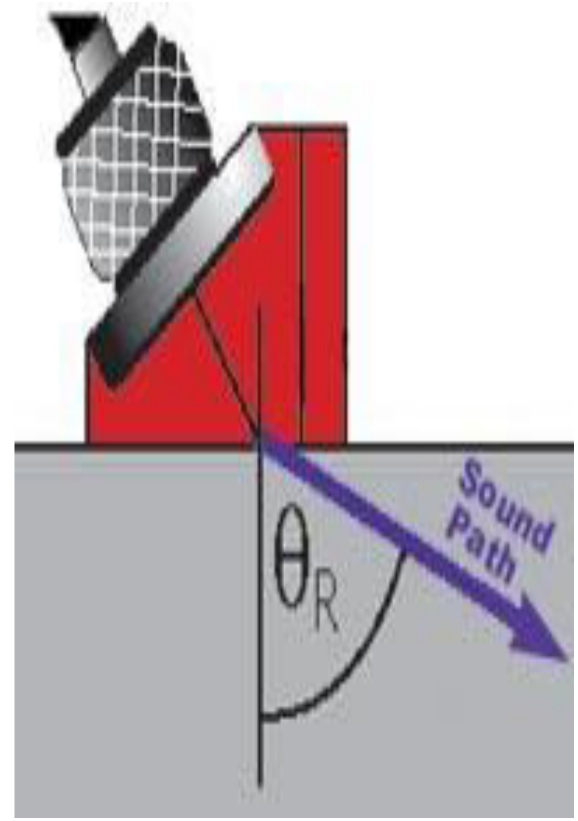
Delay line transducers

- **Delay line transducers** provide versatility with a variety of replaceable options. Removable delay line, surface conforming membrane, and protective wear cap options can make a single transducer effective for a wide range of applications.
- As the name implies, the primary function of a delay line transducer is to introduce a time delay between the generation of the sound wave and the arrival of any reflected waves. This allows the transducer to complete its "sending" function before it starts its "listening" function so that near surface resolution is improved.
- They are designed for use in applications such as high precision thickness gauging of thin materials and de-lamination checks in composite materials.
- They are also useful in high-temperature measurement applications since the delay line provides some insulation to the piezoelectric element from the heat.



Angle beam transducers

- **Angle beam transducers** and wedges are typically used to introduce a refracted shear wave into the test material.
- Transducers can be purchased in a variety of fixed angles or in adjustable versions where the user determines the angles of incidence and refraction.
- In the fixed angle versions, the angle of refraction that is marked on the transducer is only accurate for a particular material, which is usually steel.
- The angled sound path allows the sound beam to be reflected from the backwall to improve detectability of flaws in and around welded areas.
- They are also used to generate surface waves for use in detecting defects on the surface of a component.

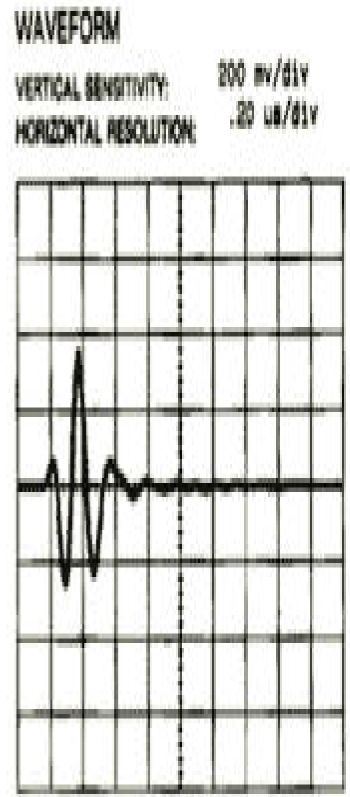


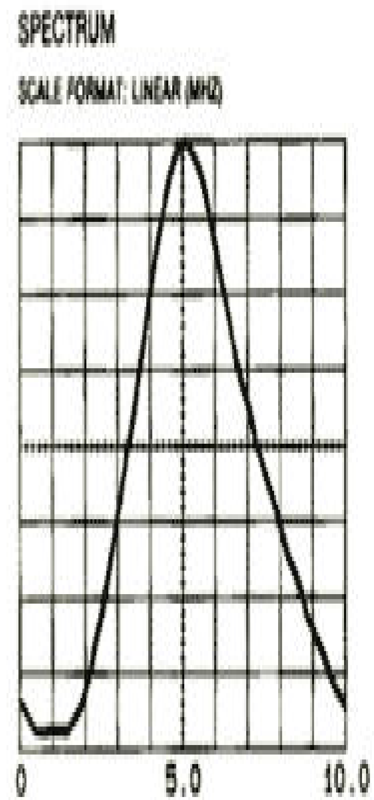
- **Normal incidence shear wave transducers** are unique because they allow the introduction of shear waves directly into a test piece without the use of an angle beam wedge. Careful design has enabled manufacturing of transducers with minimal longitudinal wave contamination. The ratio of the longitudinal to shear wave components is generally below -30dB.

- **Paint brush transducers** are used to scan wide areas. These long and narrow transducers are made up of an array of small crystals that are carefully matched to minimize variations in performance and maintain uniform sensitivity over the entire area of the transducer. Paint brush transducers make it possible to scan a larger area more rapidly for discontinuities. Smaller and more sensitive transducers are often then required to further define the details of a discontinuity.

Transducer Testing

- Manufacturers often provide time and frequency domain plots for each transducer. The signals below were generated by a spiked pulser. The waveform image on the left shows the test response signal in the time domain (amplitude versus time). The spectrum image on the right shows the same signal in the frequency domain (amplitude versus frequency). The signal path is usually a reflection from the back wall (fused silica) with the reflection in the far field of the transducer.





Transducer testing

- **Electrical Impedance Plots** provide important information about the design and construction of a transducer and can allow users to obtain electrically similar transducers from multiple sources.
- **Beam Alignment Measurements** provide data on the degree of alignment between the sound beam axis and the transducer housing. This information is particularly useful in applications that require a high degree of certainty regarding beam positioning with respect to a mechanical reference surface.
- **Beam Profiles** provide valuable information about transducer sound field characteristics. Transverse beam profiles are created by scanning the transducer across a target (usually either a steel ball or rod) at a given distance from the transducer face and are used to determine focal spot size and beam symmetry. Axial beam profiles are created by recording the pulse-echo amplitude of the sound field as a function of distance from the transducer face and provide data on depth of field and focal length.

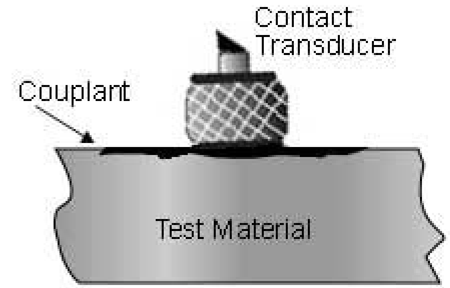
Transducer testing

- In the ASTM E1065 Standard Guide for Evaluating Characteristics of Ultrasonic Transducers, the acoustic and electrical characteristics which can be described from the data, are obtained from specific procedures

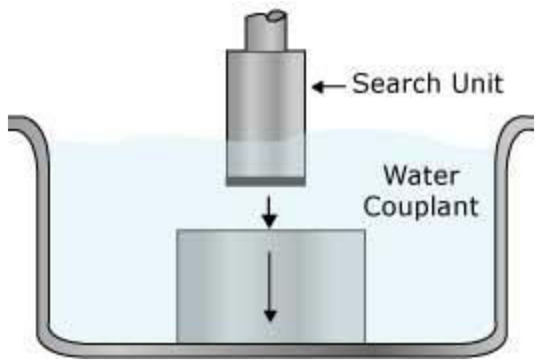
- **Frequency Response**--The frequency response may be obtained from one of two procedures: shock excitation and sinusoidal burst.
- **Relative Pulse-Echo Sensitivity**--The relative pulse-echo sensitivity may be obtained from the frequency response data by using a sinusoidal burst procedure. The value is obtained from the relationship of the amplitude of the voltage applied to the transducer and the amplitude of the pulse-echo signal received from a specified target.
- **Time Response**--The time response provides a means for describing the radio frequency (RF) response of the waveform. A shock excitation, pulse-echo procedure is used to obtain the response. The time or waveform responses are recorded from specific targets that are chosen for the type of transducer under evaluation, for example, immersion, contact straight beam, or contact angle beam.

- **Frequency Response**--The frequency response of the above transducer has a peak at 5 MHz and operates over a broad range of frequencies. Its bandwidth (3.3 to 7.3 MHz) is measured at the -6 dB points, or 50% of the peak frequency. The useable bandwidth of broadband transducers, especially in frequency analysis measurements, is often quoted at the -20 dB points. Transducer sensitivity and bandwidth (more of one means less of the other) are chosen based on inspection needs.
- **Complex Electrical Impedance**--The complex electrical impedance may be obtained with commercial impedance measuring instrumentation, and these measurements may provide the magnitude and phase of the impedance of the search unit over the operating frequency range of the unit. These measurements are generally made under laboratory conditions with minimum cable lengths or external accessories and in accordance with specifications given by the instrument manufacturer. The value of the magnitude of the complex electrical impedance may also be obtained using values recorded from the sinusoidal burst.
- **Sound Field Measurements**--The objective of these measurements is to establish parameters such as the on-axis and transverse sound beam profiles for immersion, and flat and curved transducers. These measurements are often achieved by scanning the sound field with a hydrophone transducer to map the sound field in three dimensional space. An alternative approach to sound field measurements is a measure of the transducer's radiating surface motion using laser interferometry.

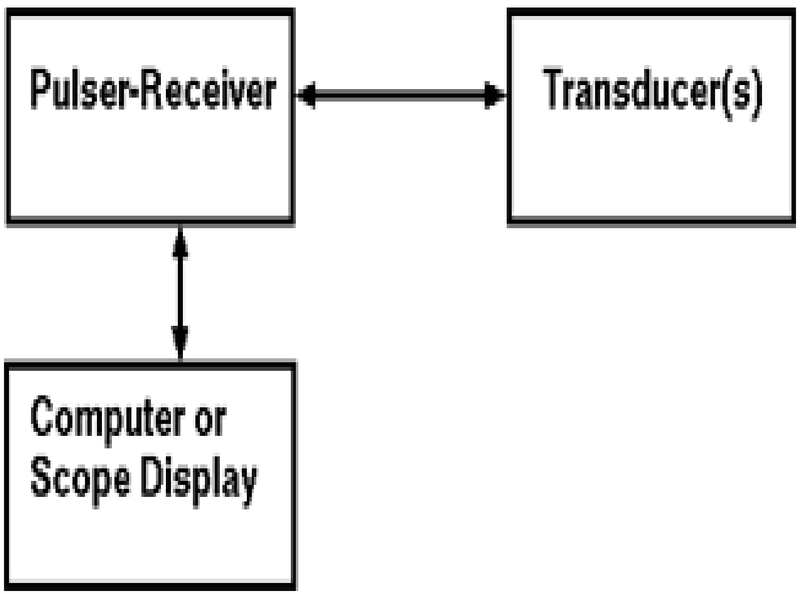
Couplant



- A couplant is a material (usually liquid) that facilitates the transmission of ultrasonic energy from the transducer into the test specimen.
- Couplant is generally necessary because the acoustic impedance mismatch between air and solids (i.e. such as the test specimen) is large.
- Therefore, nearly all of the energy is reflected and very little is transmitted into the test material.
- The couplant displaces the air and makes it possible to get more sound energy into the test specimen so that a usable ultrasonic signal can be obtained.
- In contact ultrasonic testing a thin film of oil, glycerin or water is generally used between the transducer and the test surface.

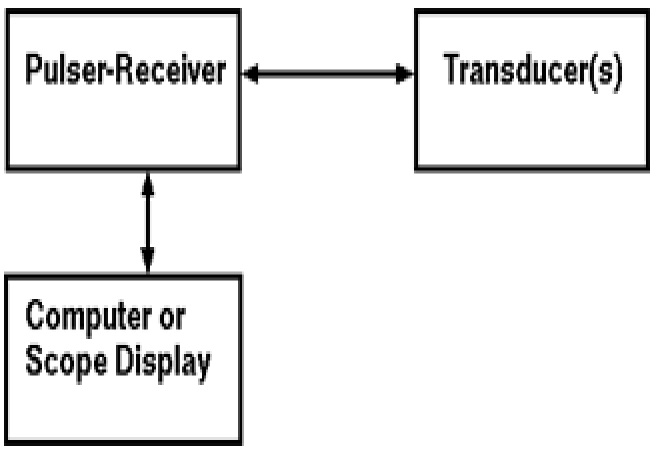


Pulser-receiver



- Control functions associated with the **<u>pulser circuit</u>** include:
- Pulse length or damping (The amount of time the pulse is applied to the transducer.)
- Pulse energy (The voltage applied to the transducer. Typical pulser circuits will apply from 100 volts to 800 volts to a transducer.)

Pulser-receiver

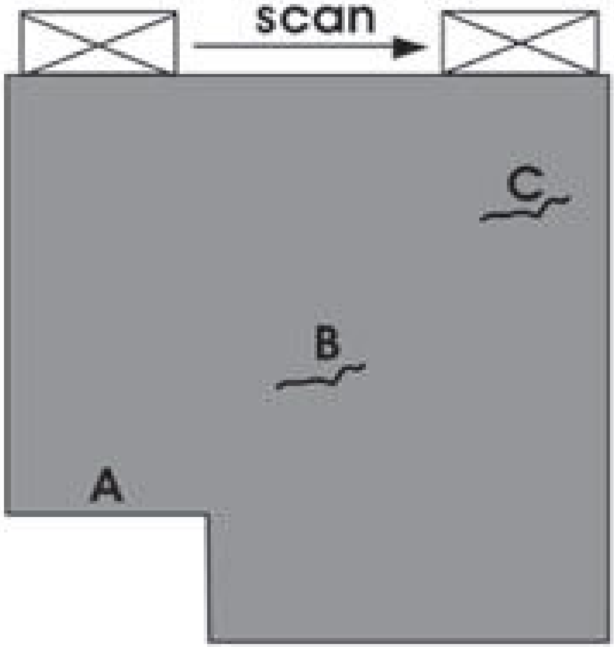


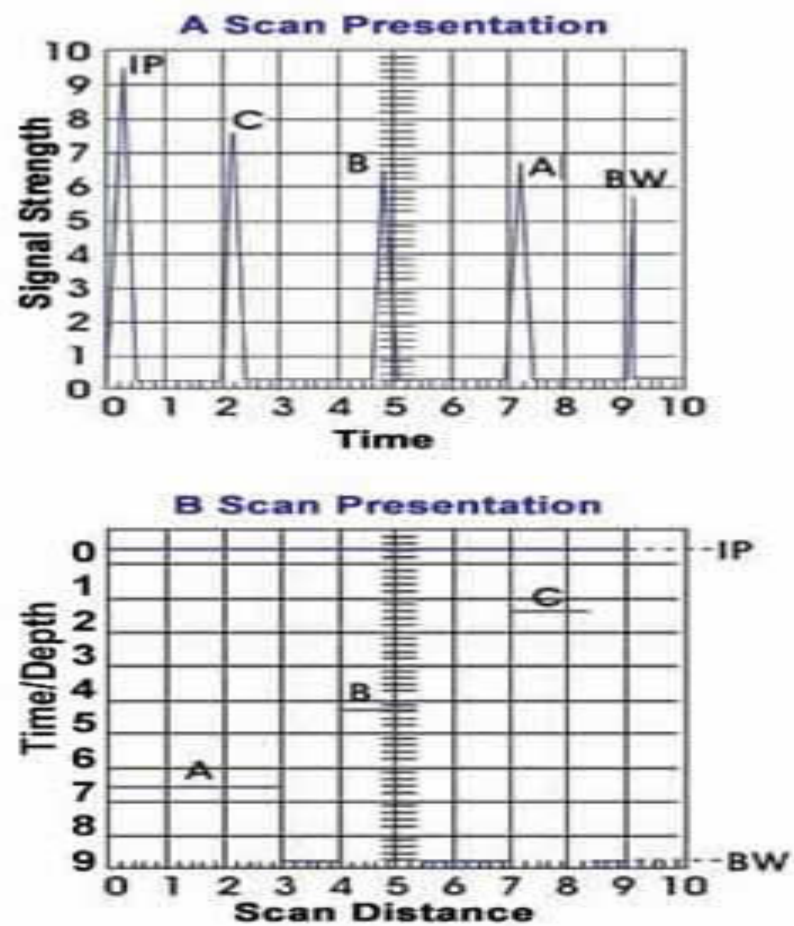
- Control functions associated with the **receiver circuit** include
- Signal rectification (The RF signal can be viewed as positive half wave, negative half wave or full wave.)
- Filtering to shape and smooth return signals
- Gain, or signal amplification
- Reject control

Data Presentation

- Ultrasonic data can be collected and displayed in a number of different formats.
- The three most common formats are know in the NDT world as **A-scan**, **B-scan** and **C-scan** presentations.
- Each presentation mode provides a different way of looking at and evaluating the region of material being inspected.
- Modern computerized ultrasonic scanning systems can display data in all three presentation forms simultaneously.

Data Presentation





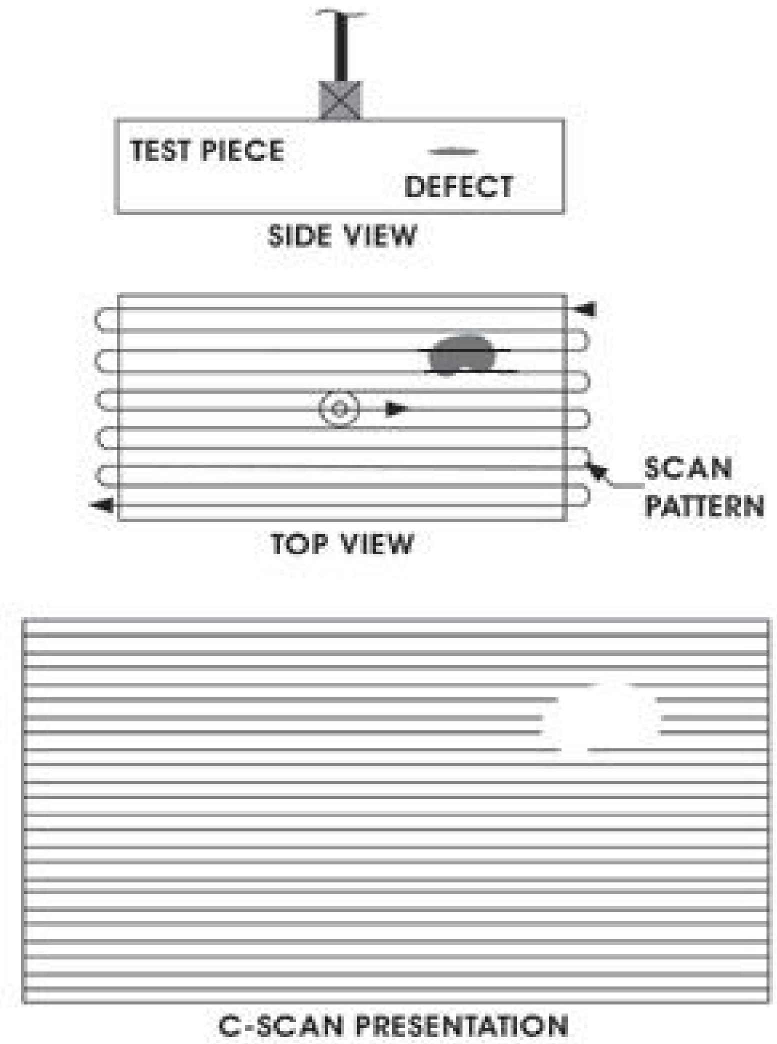
A-scan

- Echoes are displayed just as seen on an ordinary oscilloscope:X- represents the time of flight of the pulses converted into distance travelled by the pulses(depth of penetration); deflection parallel to the Y-axis represents the amplitude of the echoes.
- One dimensional information.

B-scan

- In B scan display, the Y-axis is used in a different way. When moving the probe along a straight line on the surface of the test object, the displacement of the probe can be converted into an electrical signal (voltage) by a potentiometer and used to shift the spot on the oscilloscope screen.
- This dimension is normally displayed along the x-axis and the travel of the ultrasonic pulse in the object is represented by the time base moving the spot in the y-direction(usually from the top downwards).

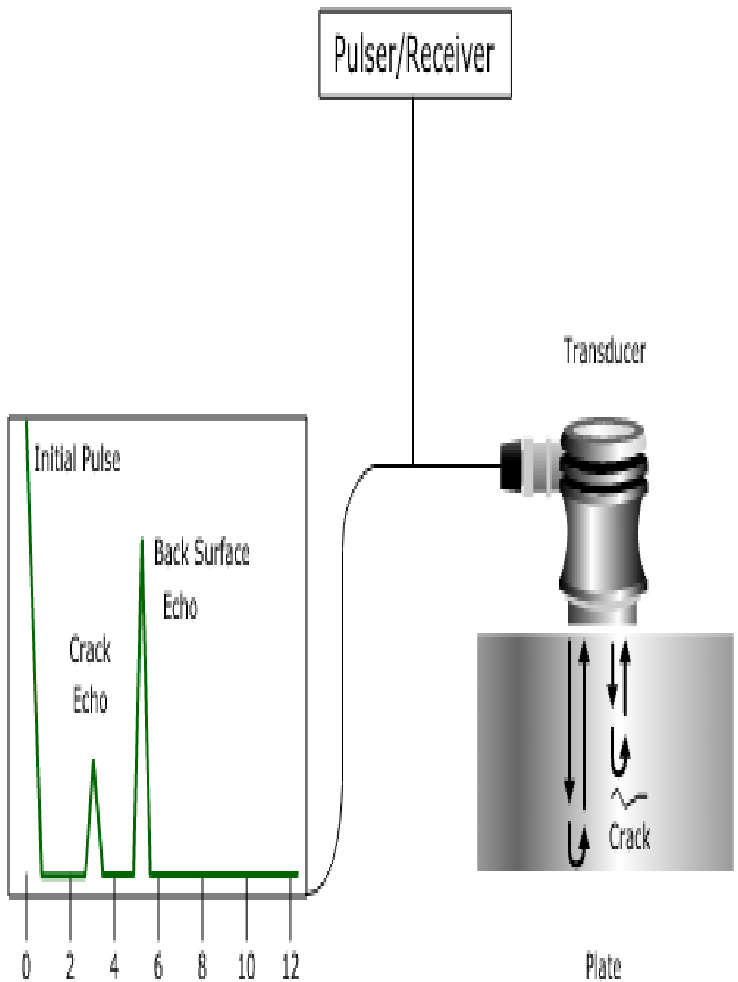
C-scan



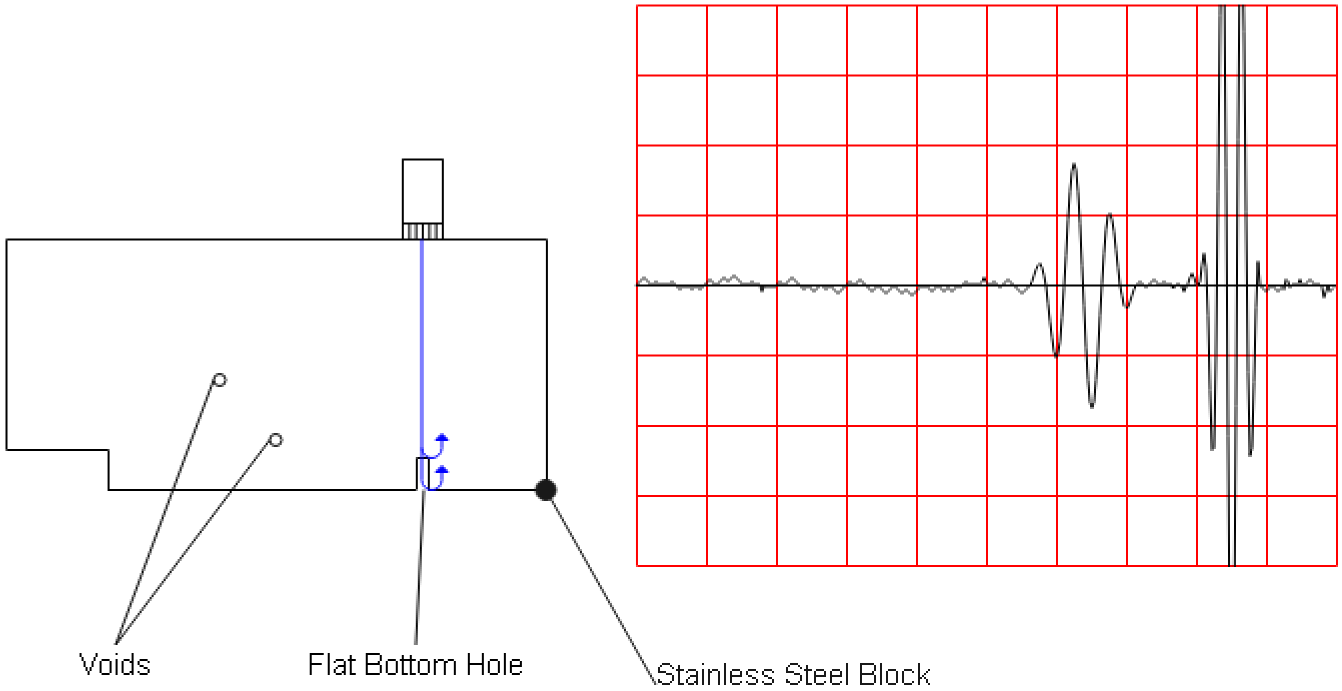
- The C-scan presentation provides a plan-type view of the location and size of test specimen features.
- The plane of the image is parallel to the scan pattern of the transducer. C-scan presentations are produced with an automated data acquisition system, such as a computer controlled immersion scanning system.
- Typically, a data collection gate is established on the A-scan and the amplitude or the time-of-flight of the signal is recorded at regular intervals as the transducer is scanned over the test piece.
- The relative signal amplitude or the time-of-flight is displayed as a shade of gray or a color for each of the positions where data was recorded.
- The C-scan presentation provides an image of the features that reflect and scatter the sound within and on the surfaces of the test piece.

Measurement Techniques

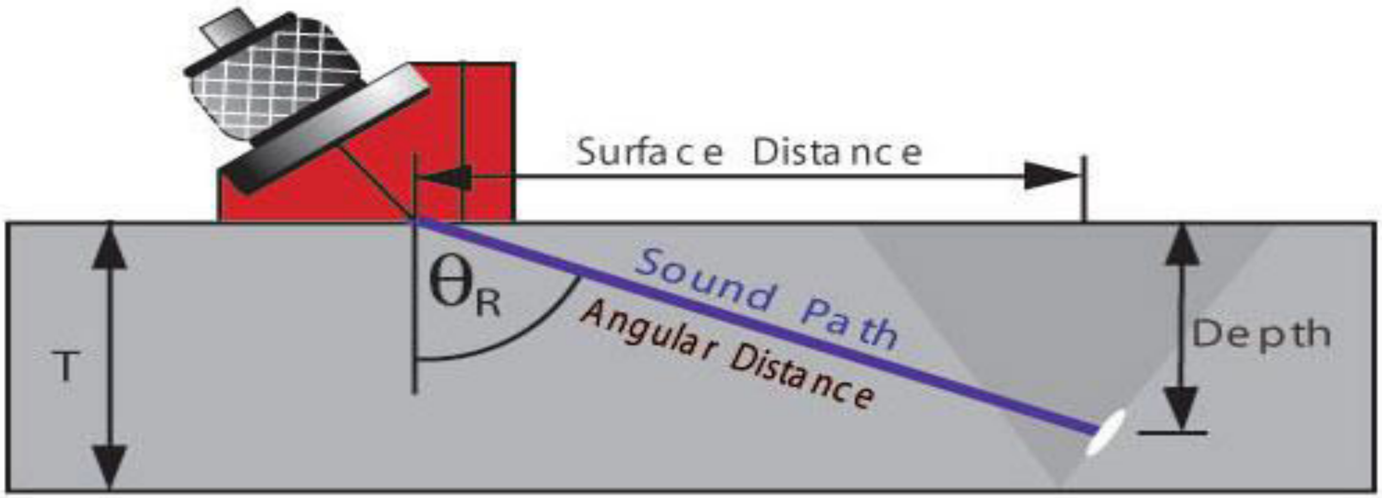
Normal Beam Inspection



- Pulse-echo ultrasonic measurements can determine the location of a discontinuity in a part or structure by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through a thickness of material, reflect from the back or the surface of a discontinuity, and be returned to the transducer. In most applications, this time interval is a few microseconds or less.
- The two-way transit time measured is divided by two to account for the down-and-back travel path and multiplied by the velocity of sound in the test material.
- The result is expressed in the well-known relationship
- **d = vt/2 or v = 2d/t**
- where **d** is the distance from the surface to the discontinuity in the test piece, **v** is the velocity of sound waves in the material, and **t** is the measured round-trip transit time.


Voids
Flat Bottom Hole
Stainless Steel Block

Angle Beam Inspection



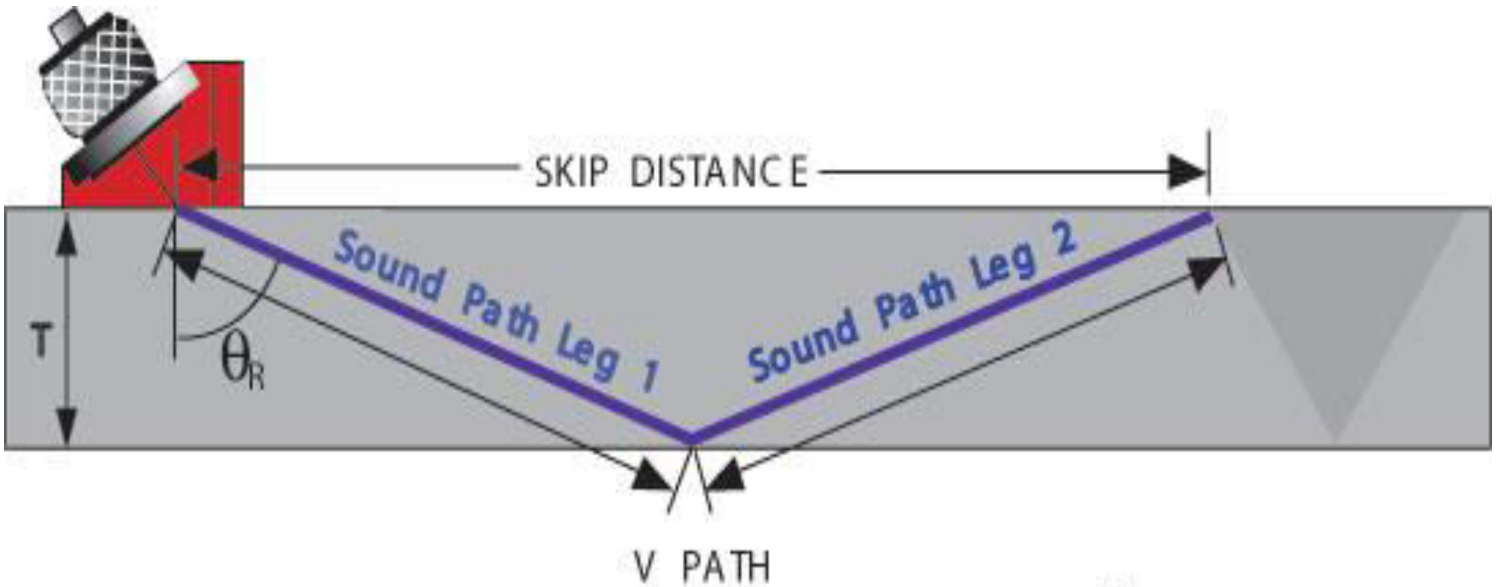
θ_R = Angle of Refraction

T = Material Thickness

Surface Distance = $\sin\theta_R \times$ Sound Path

Depth (1st Leg) = $\cos\theta_R \times$ Sound Path

Angle Beam Inspection



θ_R = Refracted Angle

T = Material Thickness

Skip Distance = $2T \times \tan\theta_R$

$$\text{Leg} = \frac{T}{\cos\theta_R}$$

$$\text{V-Path} = \frac{2T}{\cos\theta_R}$$

Advantages

- High sensitivity
- Permitting detection of minute discontinuities.
- Good penetrating power, allowing examination of extremely thick sections.
- Accuracy in the measurement of discontinuity position and estimation of discontinuity size.
- Fast response, permitting rapid and automatic testing
- Need for access to only one surface of the test object for most applications.

Disadvantages

- Unfavorable test object geometry(size, contour, surface roughness, complexity and discontinuity orientation,)
- Undesirable internal structure(grain size, structure porosity, inclusion content or fine, dispersed precipitates)

Applications

Rail Inspection

Wheel Probe Used in Railroad Rail Inspection