Rohini College of Engineering and Technology
(Autonomous)

DEPARTMENT OF MECHANICAL ENGINEERING

OML351
INTRODUCTION TO NON-DESTRUCTIVE TESTING

Ultrasonic Testing-Principle, Transducers, transmission and pulse-echo method, straight beam and angle beam, instrumentation, data representation, A/Scan, B-scan, C-scan. Phased Array Ultrasound, Time of Flight Diffraction. Acoustic Emission Technique – Principle, AE parameters, Applications.

Introduction

In ultrasonic testing, high frequency sound energy is used to identify surface and sub-surface discontinuities.

Ultrasonic testing is completely safe method of non-destructive testing and it is extensively used in many basic manufacturing and service industries. Especially in applications of inspecting welds and structural metals.

Modes of wave propagation

Sound energy used in flaw detection travels in different wave models based in the direction of the wave and the corresponding motion of molecules in the test piece.

The most commonly used modes of wave propagations are:

i) Longitudinal waves (ii) Shear waves (iii) Surface waves (iv)Lamb waves

i) Longitudinal waves

In a longitudinal wave, particle motion in the medium is parallel to the direction of the wave front.

Longitudinal waves travel the fast of the wave modes and are commonly used in ultrasonic of metals.

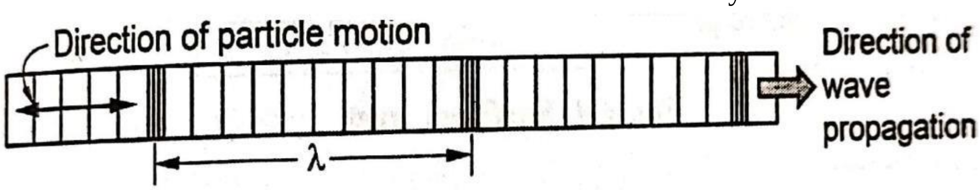

Figure. Longitudinal waves

ii) Shear waves

In a shear wave, particle motion is perpendicular to wave direction. Shear waves have a slower velocity and shorter wavelength than longitudinal waves of the same frequency.

They are used for most angle beam testing in ultrasonic flaw detection.

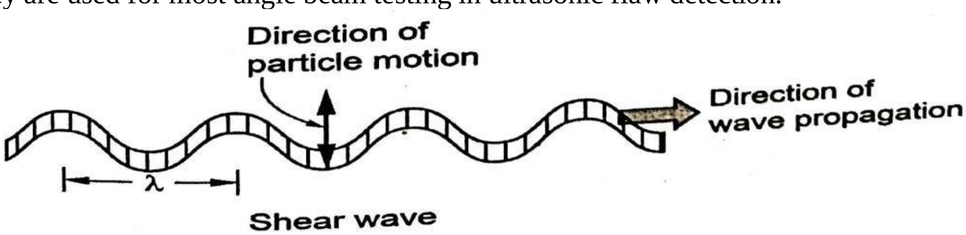

Figure. Shear waves

iii) Surface waves

Surface waves, also known as Rayleigh waves, represent an oscillating motion that travels along the surface of a test piece to a depth of one wave length. Velocity and wavelength are similar to shear waves.

Surface waves can be used to detect surface breaking cracks in a test piece.

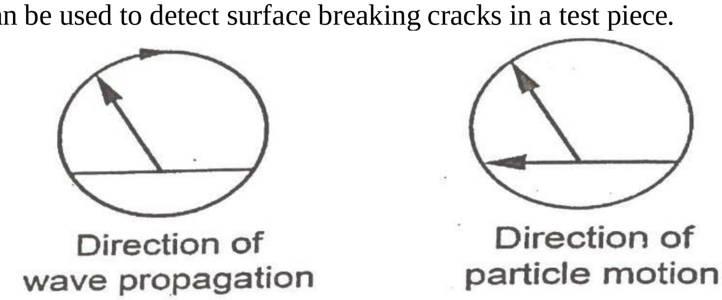

Figure. Surface waves

iv) Lamb waves

Lamb waves are surface waves propagate parallel to the test surface and a have a particle motion that is elliptical.

The occur when the thickness of test material is only a few wavelengths at the test frequency and where the test piece is uniform thickness.

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. To illustrate the general inspection principle, a typical pulse/echo inspection configuration as illustrated below will be used.

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. In the applet below, the reflected signal strength is displayed versus the time from signal generation to when a echo was received. Signal travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

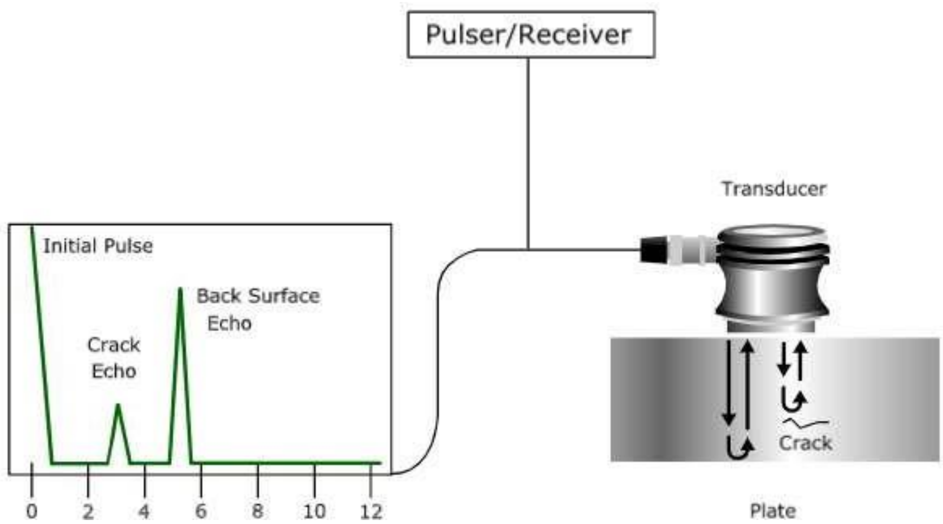

Figure. Principles of Ultrasonic Testing

Ultrasonic Inspection is a very useful and versatile NDT method. Some of the advantages of ultrasonic inspection that are often cited include:

- ✓ 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.

As with all NDT methods, ultrasonic inspection also has its limitations, which include:

- ✓ 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.

ULTRASONIC TRANSDUCERS AND THEIR CHARACTERISTICS:

Ultrasonic transducers (or probes or search units) are devices to generate and receive ultrasound. For non-destructive test purposes, piezo-electric elements of suitable dimensions are used to generate the complete range of ultrasonic frequencies at all levels of intensities. The transducers convert electrical energy into mechanical energy (vibration) and vice-versa, as explained earlier.

A transducer essentially consists of a case, a piezo-electric element, backing material, electrodes, connectors and protection for the piezo-electric element from mechanical damage. The figure shows the essential elements of a transducer assembly.

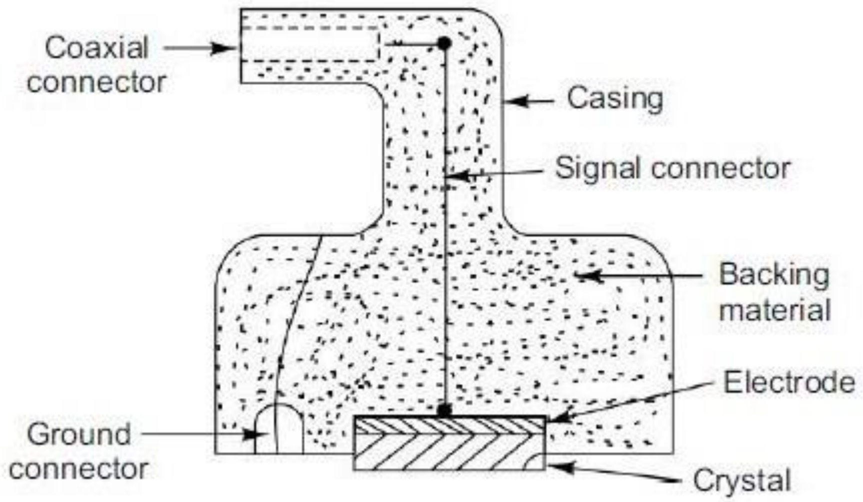

Figure *Elements of a Transducer Assembly*

A casing is the housing within which various elements are contained. It is metallic or molded plastic. When the piezo-electric element is subjected to electrical impulses, it vibrates or 'rings' for a long time. For non-destructive testing, a long period of vibration is undesirable as it adversely affects defect resolution capability. To prevent excessive ringing, highly attenuating materials (called backing materials) are bonded to the back face of the piezoelectric element. Backing materials consist of a mixture of graphite, powdered metals (e.g. tungsten) and a metal oxide of random grain size. Wear resistance of the crystal can be increased without sacrificing resolution and sensitivity by the use of a thin layer of aluminum oxide or boron carbide.

Types of Transducers:

a. Normal Beam Transducers

These transducers are used for contact testing and immersion testing. Transducers generate, transmit and receive longitudinal waves, normal to the test surface.

In the immersion type of testing, the piezoelectric element is made completely waterproof and a grounding electrode is provided in the front face.

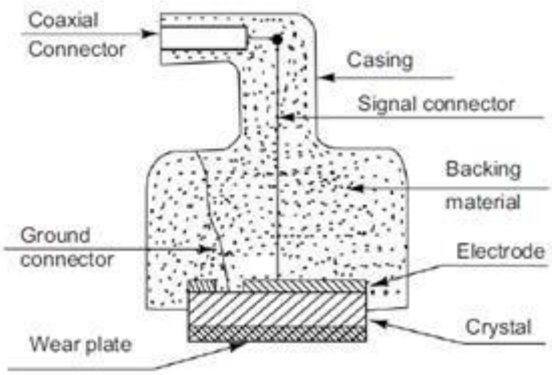

Figure *Normal Beam with Wear Plate*

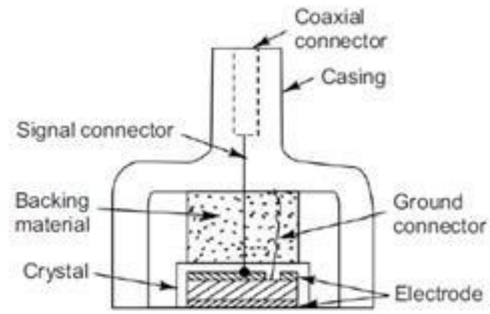

Figure *Immersion Search Unit*

b. Angle Beam Transducers

These are contact type transducers that transmit and receive longitudinal waves at an angle to the test material surface. During the transmission of the wave, the longitudinal wave is mode converted to a shear or surface wave on entering the material.

During reception, the shear or surface wave is mode converted back to the longitudinal wave. Figure shows the essential elements of an angle beam transducer. The transducer is similar to a normal beam probe, except that a wedge cut at an appropriate angle is attached to the normal beam transducer.

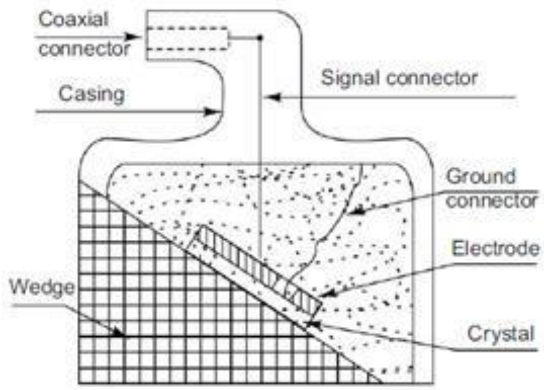

Figure *Angle Beam Contact Search Unit*

c. Dual Element Transducers

In this type, the transmitter and receiver elements are separated with a cork-divider.

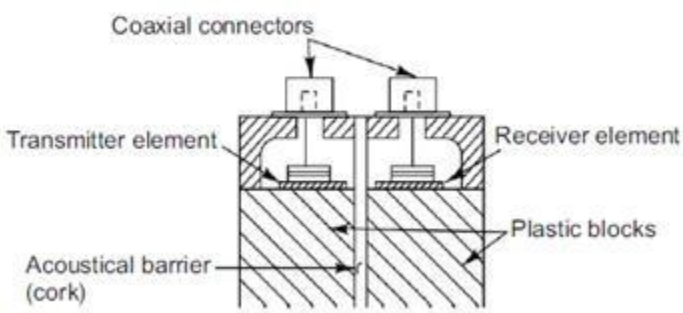

Figure *Dual Element Transducer*

d. Focused Transducers

Focused transducers are designed to concentrate acoustic energy into a small area. This improves intensity, sensitivity and resolution and also reduces the effect of acoustic noise. An acoustic lens of predetermined focal length is attached to a normal beam probe. Sometimes it is incorporated in the transducer facing. The focusing could be cylindrical or spherical. While examining curved surfaces, cylindrical focusing is used. Spherical focusing concentrates the sound beam into a cone. Spherical focusing is preferred while examining near surface defects.

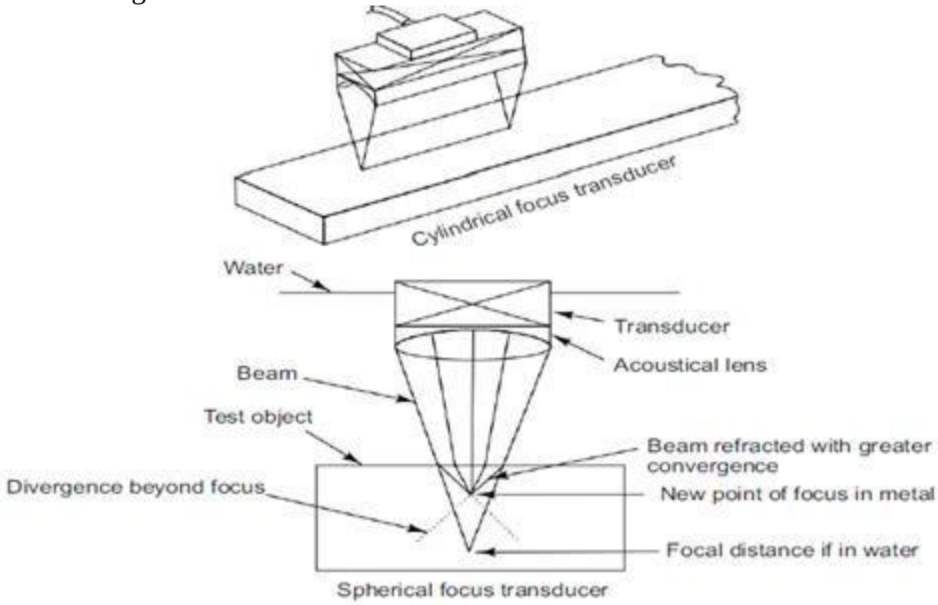

Figure *Cylindrical and Spherical Focus Transducers*

e. Noncontact Methods

EMAT (ElectroMagnetic Acoustic Transducer) technology is an alternative method of generating and receiving ultrasonic energy. These are transducers that are made up of coils that are placed in close proximity to the test piece. The coils produce a magnetic field that interacts with the metal, producing a deformation in the surface of the material. This deformation produces the wave of ultrasonic energy.

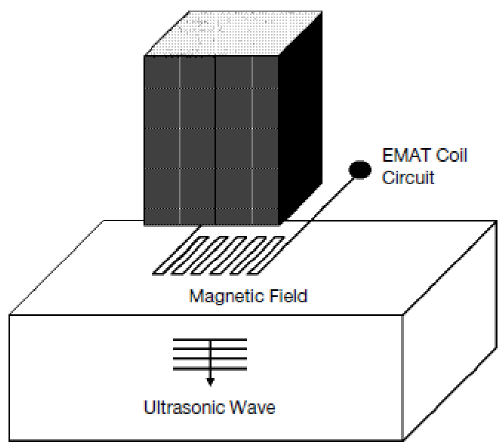

FIGURE EMAT transducer.

The advantages of EMAT:

1. There is no need for a couplant. An EMAT is a noncontact transducer.
2. They lend themselves to applications that normally have limitations, such as the examination of high-temperature components. Because this type of transducer depends on the induction of a field, the transducer has to work in close proximity to the work surface. The strength of the magnetic field is reduced as the distance between the transducer and the component surface increases.
3. The gap between the transducer and the work face need not be composed of air. Examination of components that have been coated with some protective layer is possible. It is the front surface of the component material that actually generates the ultrasonic energy.
4. Focusing of the beam is also possible, as is steering the beam at various angles.

5. Horizontally polarized shear wave energy can be produced. The polarity is important in that horizontally polarized shear waves do not mode convert when striking surfaces that are parallel to the direction of polarization. This has certain advantages, particularly when examining austenitic welds and other materials with dendritic grain structure, e.g., certain cast stainless steels.

The disadvantages include:

1. Low efficiency compared with piezoelectric transducers.
2. Relatively large transducer size.
3. Producing ultrasonic energy in nonconductive material is only possible if a conductive layer is applied to the surface.

f. Phased Array Transducers

These transducers incorporate elements that are arranged in certain patterns for the purpose of dynamically focusing or steering the energy. Sequentially pulsing the elements, using a combination of elements in the array, and timing the pulses used to excite these elements, produces a beam focused at variable depths in the test material.

Multiple wave fronts are combined to form a beam of a particular shape. Element configurations can be circular or rectangular, depending on the desired beam shape and direction of energy propagation. Linear array units are more commonly used in the medical field for imaging than in the industrial sector.

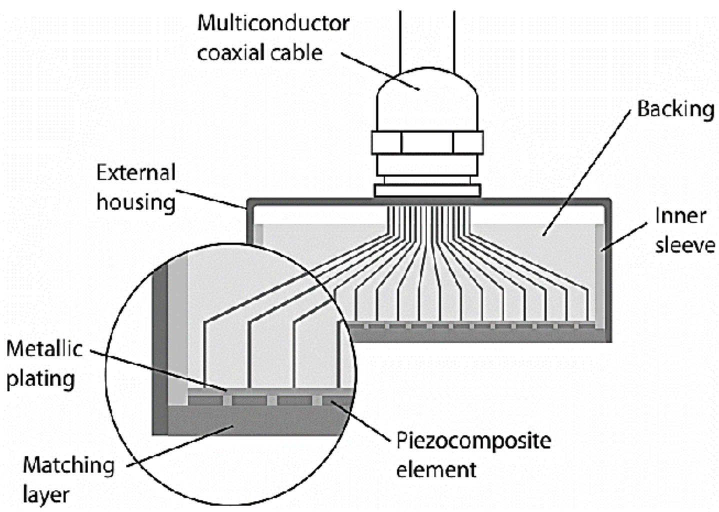

Figure. Phased Array Transducers

Various factors influencing the selection of ultrasonic transducers.

i) Material factor
ii) Geometry and surface condition
iii) Frequency
iv) Sensitivity
v) Band width
vi) Waveform duration

Basic Methods of Ultrasonic Testing:

Ultrasonic testing depends on the nature of the product, its manufacturing process, the surface condition, geometry and accessibility of the scanning area. There are three basic test methods commonly used in industries: pulse echo, through transmission and resonance.

1. Pulse echo test method:

Here, short pulses of ultrasonic waves are transmitted in the material under test. These pulses are reflected from discontinuities in their path or from any boundary of the material.

The reflected waves (or echoes) are received by the same transducer and are displayed on the CRT, which provides the following information:

- ✓ The relative size of the discontinuity in terms of the amplitude of the signal displayed on the CRT

- ✓ The depth of the discontinuity on the CRT time base scale, which is appropriately calibrated in terms of known material thickness
- ✓ In this method, a single transducer is used both as transmitter and receiver of the waves. Sometimes two transducers are used, one as transmitter and the other as receiver

The main advantage of this method is that only one surface of the test object is required for testing and the method is capable of providing size as well as depth location of the discontinuity.

However, a limitation is that the material immediately below the transducer contact surface, with in the near zone, cannot be examined unless the appropriate delay shoe is attached to the transducer in contact testing or a suitable length of water column is provided in immersion testing.

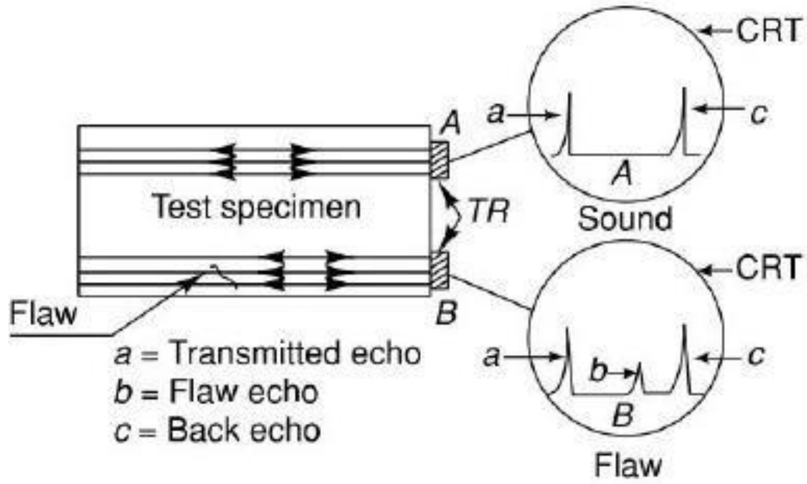

Figure *Pulse Echo System*

2. Through transmission method:

Two transducers are used here, one as transmitter, the other as receiver. Short pulses of waves are transmitted into the material. The test method requires access to two nearly parallel surfaces of the test object. The receiver transducer is aligned properly with the transmitter transducer on the opposite side of the test object to pick up the ultrasonic waves passing through the material.

The soundness or quality of the test material is evaluated in terms of energy lost as the ultrasound travels through the material. The presence of a discontinuity is indicated by variations in the energy amplitude. A significant reduction in energy amplitude indicates a discontinuity.

The main disadvantage of this method is its inability to locate the defect. Misalignment of the search unit can also create an interpretation problem. An advantage of the through transmission system is better near surface resolution.

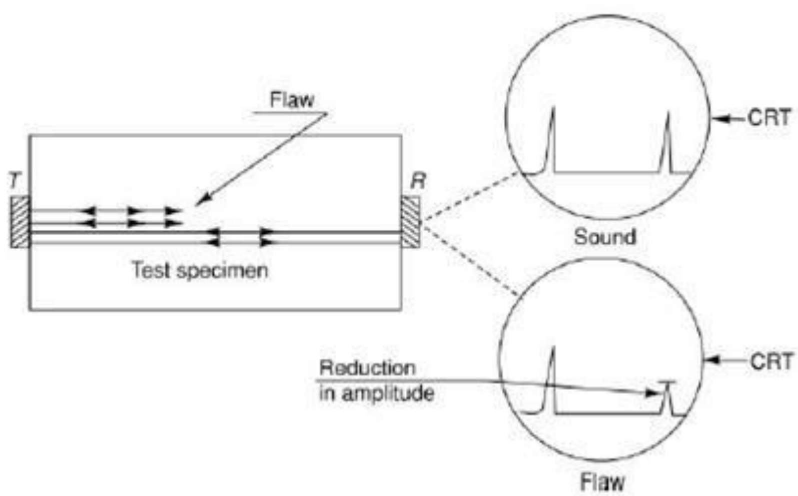

Figure *Through Transmission System*

3. Resonance system:

This system makes use of the resonance phenomenon to measure material thickness and to determine the bond quality of a test object.

Continuous longitudinal waves are transmitted into the material and the wave frequency is varied until standing waves are set up within the specimen, causing the specimen to vibrate at greater amplitude. At resonance, the specimen thickness is equal to one half or multiples of a wavelength.

Resonance is detected by an indicator device and is presented on the CRT screen as a 'pip' as shown in Fig below.

A disadvantage of this system is that the accuracy of the test reduces as the material thickness increases.

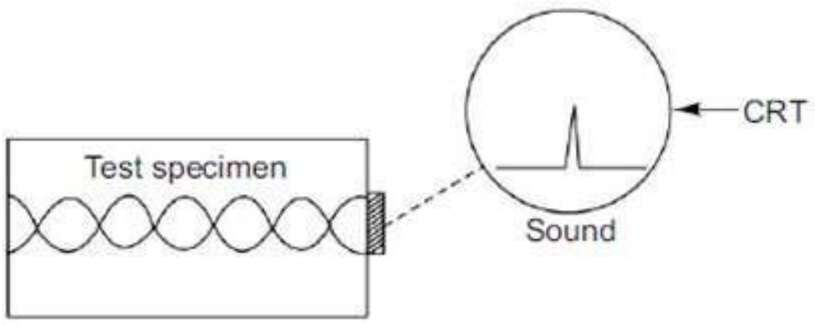

Figure *Resonance System*

EQUIPMENT FOR ULTRASONIC TESTING

- ✓ Ultrasonic systems are either battery operated portable units or multi-component laboratory ultrasonic systems.
- ✓ Basically ultrasonic equipment comprise the following components:
  1. Pulser /receiver,
  2. Ultrasonic transducer,
  3. Couplant,
  4. Display (Screen)
  5. Receiver / Amplifier

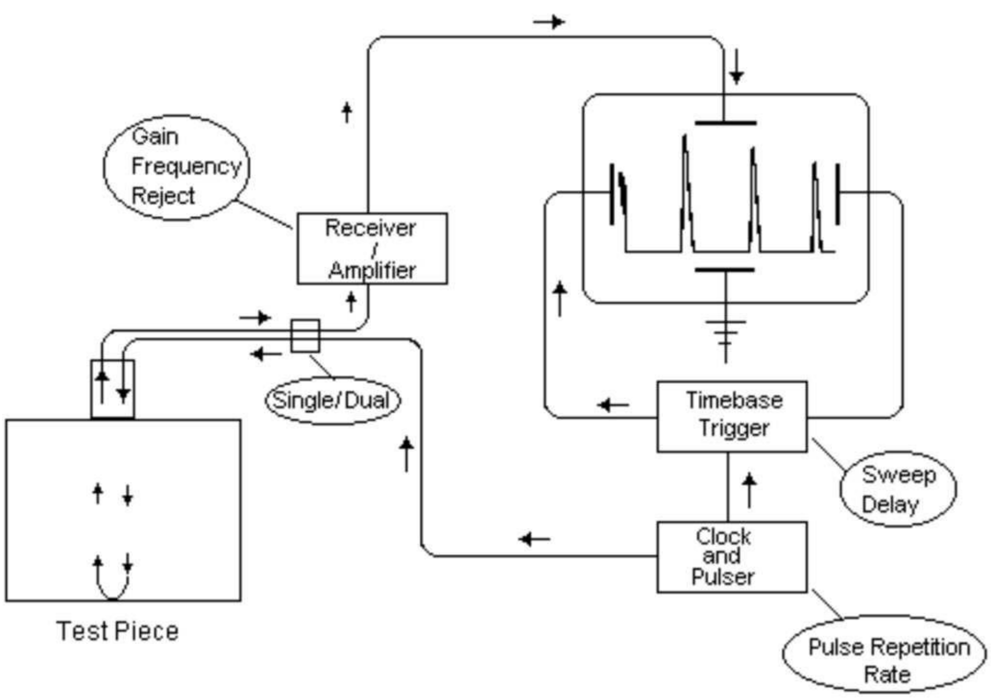

Figure. Basic components of ultrasonic equipment

1. Pulser/Receiver

- ✓ High voltage pulse required by ultrasonic transducer is generated by this circuit. Ultrasonic waves are produced by large amplitude electric pulses. A short burst of alternating electrical energy is called as pulse.
- ✓ Apart from generation of pulses, this circuit also acts as a receiver of signals coming from transducer.

2. Ultrasonic Transducer

- ✓ Transducer, also called search unit, in ultrasonic inspection is pulsed and sending out an ultrasonic wave. The subsequent echoes generate a voltage in the transducer, which is sent back to the pulser/receiver

3. Couplant

- ✓ Couplant is used to reduce the air gap between the transducer and surface of the part to be inspected.
- ✓ A very thin layer of air will severely retard the transmission of sound waves from the transducer to the material being inspected
- ✓ To avoid the transmission problem couplants are used in both contact as well as immersion techniques.

4. Display/Oscilloscope

It is a device on which received data/signal is displayed either in video mode or in radio frequency mode.

5. Receiver/Amplifier

The voltage signals received by receiver from ultrasonic transducer are amplified where amplified radio frequency are available as an output display on oscilloscope.

Ultrasonic Inspection Techniques:

1. Straight beam ultrasonic inspection method
2. Angle beam ultrasonic inspection method
3. Time of flight diffraction (TOFD) method
4. Phased array ultrasonic inspection method
5. Immersion ultrasonic inspection method

a. Angle beam ultrasonic inspection method:

An ultrasonic beam is transmitted into the test specimen at an angle to the test surface. To achieve this, the piezo-electric element is mounted on a plastic wedge at the desired angle. The flat edge of the wedge is placed on the test surface as shown in Figure a.

When the angle of the incident beam is other than normal to the test surface, refracted longitudinal and shear wave components are produced due to mode conversion. Longitudinal waves are originally produced in the wedge but it is possible to have either longitudinal or shear waves in the test specimen. Both may be present at the same time depending upon the angle of the wedge.

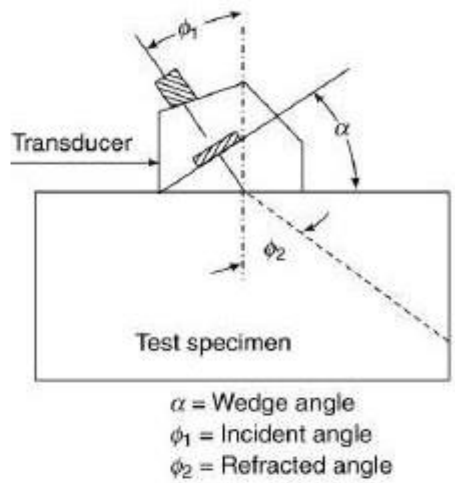

Figure.a *Angle Beam Technique*

As the angle of incidence is increased to the second critical angle, when the shear wave travels parallel to the surface, a surface wave mode is developed in the medium. This wave can penetrate the medium to the extent of one wavelength. This wave pattern is known as ‘surface wave’ or ‘Rayleigh wave’ and its velocity is about 90% of the velocity of shear waves. These waves are used for detecting surface discontinuities in the contact mode of testing. The waves follow the contour of the test specimen around fillet radii and other irregular surface features. Figure b illustrates this.

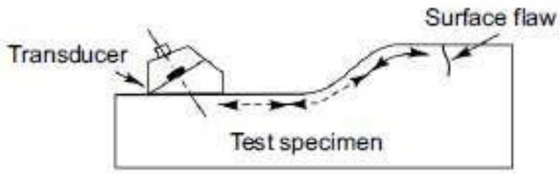

Figure b.*Surface Wave Testing*

In very thin sheets, the angular incidence of the sound beam and mode conversion at the interface produces plate or lamb waves. The velocity of these waves depends on the type of material, the frequency, and the velocity in the wedge material, the angle of the wedge and the plate thickness. Various applications of these waves are given in Table below

TABLE *Application of shear, surface and plate waves*

Testing Method	*Typical Applications*
Shear waves	Inspection of welds, plates, pipes, tubing and complex geometry forging and castings
Surface waves	Inspection of surface defects (e.g. heat treatment cracks, fatigue cracks, tool marks, stress raisers, etc.)
Plate waves	Detection of laminations in thin materials, lack of bonding in composite materials

b. Phased array ultrasonic inspection method

Phased Array Ultrasonic Testing (PAUT) is an advanced nondestructive examination technique that utilizes a set of ultrasonic testing (UT) probes made up of numerous small elements, each of which is pulsed individually with computer-calculated timing (“phasing”).

When these elements are excited using different time delays, the beams can be steered at different angles, focused at different depths, or multiplexed over the length of a long array, creating the electronic movement of the beam. Phased array probes can be used manually in a free running mode scrubbing the surface of a component, attached to an encoder to record position, or mounted on a semi-automated or motorized scanner for optimum productivity.

Using phased array probes in direct contact with the component, whether mounted on a hard wedge, a water delay line, or even inside a wheel probe, gives inspectors the ability to quickly scan large areas for corrosion, cracking, and other defects with high resolution.

PAUT can be used to inspect almost any material where traditional UT methods have been utilized and is often used for weld inspections and crack detection.

c. Time of Flight Diffraction (TOFD) Technique.

The TOFD technique, first used by M. G.Silk in 1977, uses tip diffraction to identify the top, bottom, and ends of a discontinuity in one pass. Silk chose to use an angled compression wave for the TOFD technique rather than a shear wave, for two reasons.

First, the tip diffraction signal is stronger than a shear wave diffraction signal, and second, a lateral wave is produced that can be used to measure the horizontal distance between the transmitter and receiver.

The tip diffraction signal is generated at the tip of the discontinuity—effectively a “point” source. According to Huygens, a point source produces a spherical beam.

Figure a. shows both the lateral wave and a diffraction beam from the tip of a reflector.

Figure b. shows a typical TOFD transducer set-up on a component with a vertical discontinuity. There are four sound paths from the transmitter to the receiver. Path “A” is the lateral wave path traveling just below the surface. Path “B” is the tip diffraction path from the top of the discontinuity. Path “C” is the tip diffraction path from the bottom of the discontinuity, and path “D” is the back wall echo path.

Figure c. shows a typical unrectified trace for the four signals. Note that the phase relationships A and C are in opposite phase to B and D. The important difference to note is between B and C—the top and bottom diffraction signals are in opposite phase. This phase difference allows the practitioner to identify those points.

Assuming that the diffracting tip is centered between the two transducers, the depth of the tip below the surface can be calculated from

$$depth = \sqrt{\left(\frac{BPL}{2}\right)^2 - \left(\frac{HD}{2}\right)^2}$$

where
BPL = beam path length for the signal in question
HD = beam path length for the lateral wave

The distance measurements taken from the ultrasonic trace must be made from the same part of each waveform. In the example trace shown in Figure c., the largest half cycle would be selected. For signals A and C, this is negative, and for signal B, positive.

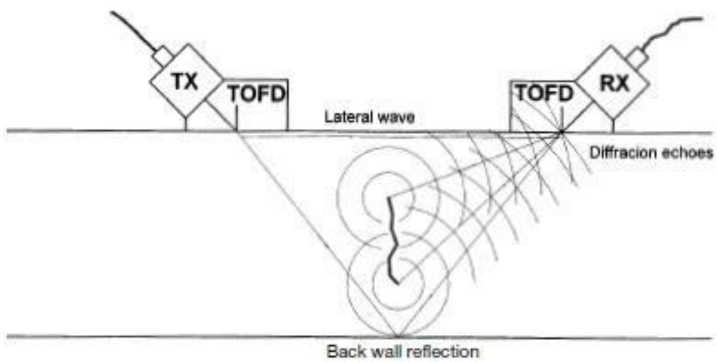

Figure a. TOFD

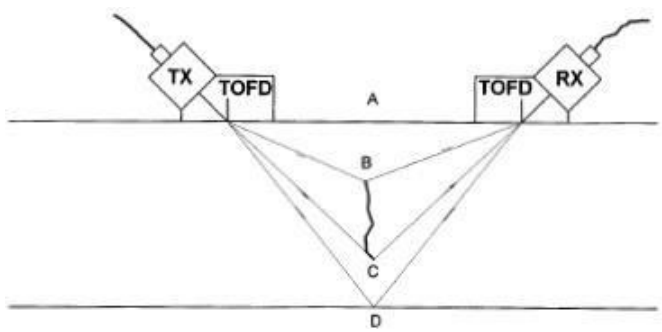

Figure b. TOFD

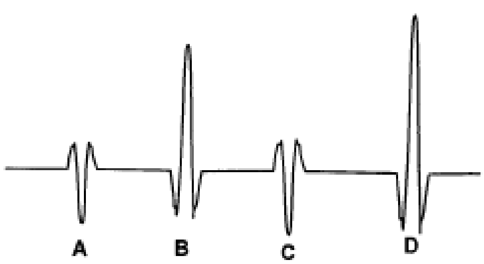

Figure c. TOFD RF signals

Advances in computer technology have made it possible to carry out all the calculations and for plotting to be handled automatically and stored for subsequent evaluation. The method that has been chosen to display this TOFD data presents the information in a special “B-scan” form that is easy to assimilate.

d. Immersion ultrasonic inspection method:

In the immersion method, the test specimen and the leak-proof transducer are immersed in a liquid, usually water. The liquid acts as a couplant.

This method provides testing flexibility. The transducer can be moved under water at any desired angle. Further, the transducer does not contact the specimen and is therefore not subjected to wear. Higher frequencies can be employed, enhancing defect detection efficiency.

Immersion testing is employed for high speed and automatic scanning. Figures a & b illustrate the immersion pulse-echo normal probe and immersion pulse echo angle probe methods.

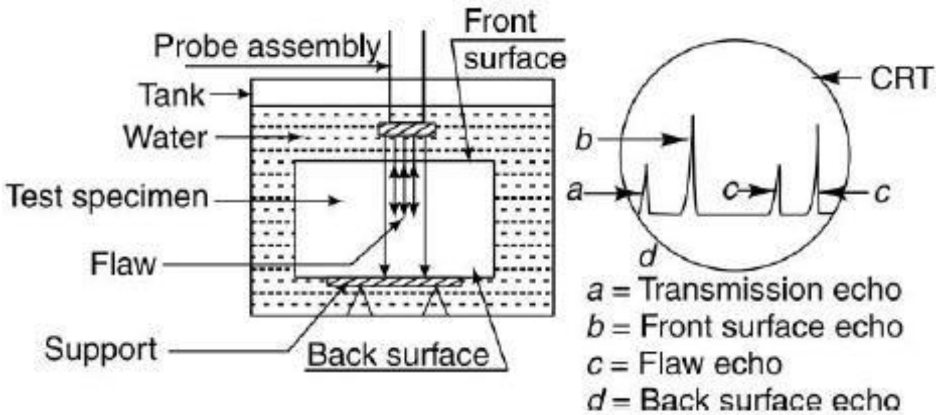

Figure a *Immersion Pulse Echo Method*

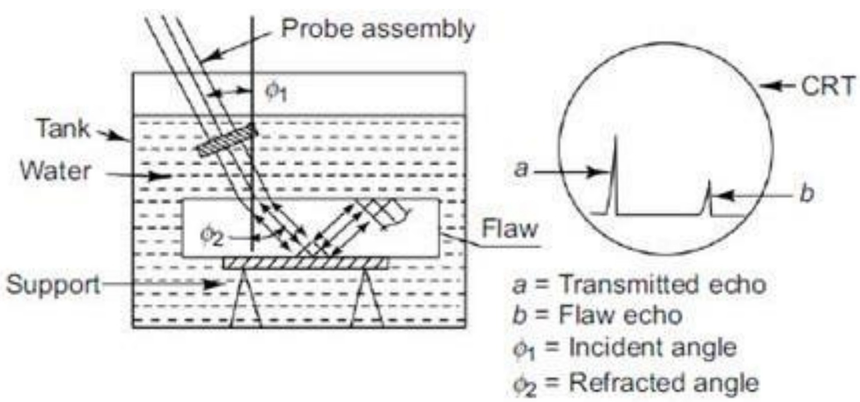

Figure b *Immersion Angle Beam Method, Using Longitudinal Waves*

It is important to appreciate that shear waves cannot be used in a fluid; therefore, only longitudinal waves are used and introduced into the medium at an angle, with the help of manipulators.

Longitudinal waves entering the medium get mode-converted as shear waves at an angle. After reflection from any defect or boundary, the transverse wave gets mode-converted and travels back to the transducer as a longitudinal wave.

In the through transmission immersion technique, the specimen is immersed in a liquid couplant, usually water. A separate transmitter and receiver are axially adjusted through manipulators.

Ultrasonic energy is transmitted into the specimen, which is mounted on a special fixture, for easy adjustment. Any defect in the path of the ultrasonic beam causes a shadow and hence, a reduction in the intensity of the beam. Figure c illustrates the test system.

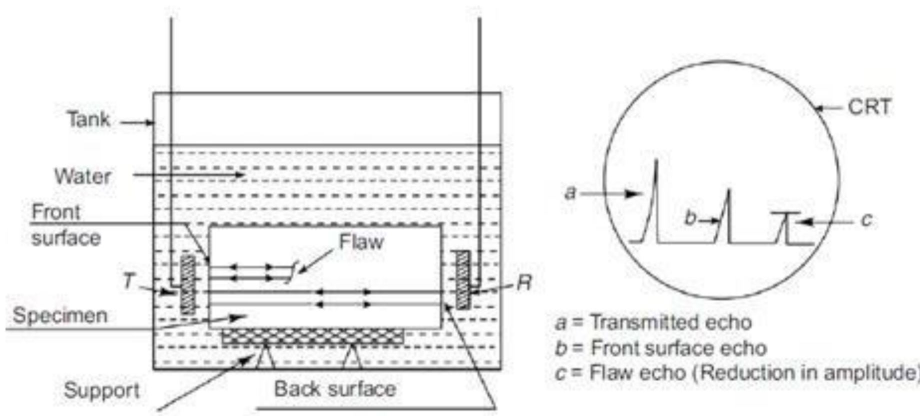

Figure c *Through Transmission Immersion System*

Further, to reduce the difficulty in interpretation, the water path, that is the distance between the transducer and the front surface of the specimen, should be selected such that the ultrasonic transit time in the liquid column is greater than the ultrasonic transit time between the front and back surfaces of the test material.

DATA PRESENTATION

Ultrasonic data can be collected and displayed in a number of different formats. The three most common formats are known 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.

A-Scan Presentation

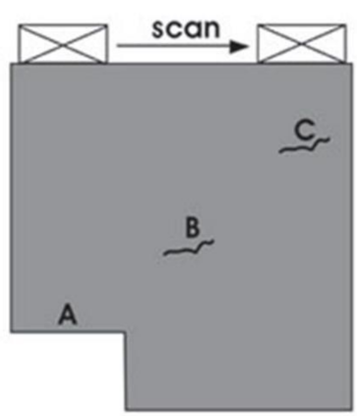

Figure. Data Representation about the defects

The A-scan presentation displays the amount of received ultrasonic energy as a function of time. The relative amount of received energy is plotted along the vertical axis and the elapsed time (which may be related to the sound energy travel time within the material) is displayed along the horizontal axis.

Most instruments with an A-scan display allow the signal to be displayed in its natural radio frequency form (RF), as a fully rectified RF signal, or as either the positive or negative half of the RF signal. In the A-scan presentation, relative discontinuity size can be estimated by comparing the signal amplitude obtained from an unknown reflector to that from a known reflector. Reflector depth can be determined by the position of the signal on the horizontal sweep.

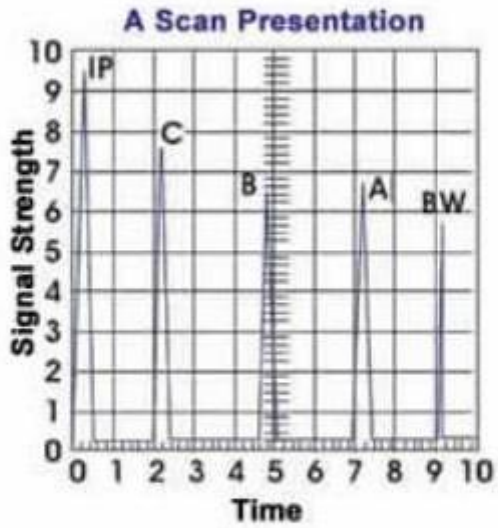

Figure. A-Scan Presentation

In the illustration of the A-scan presentation to the right, the initial pulse generated by the transducer is represented by the signal IP, which is near time zero.

As the transducer is scanned along the surface of the part, four other signals are likely to appear at different times on the screen.

When the transducer is in its far left position, only the IP signal and signal A, the sound energy reflecting from surface A, will be seen on the trace.

As the transducer is scanned to the right, a signal from the backwall BW will appear later in time, showing that the sound has traveled farther to reach this surface.

When the transducer is over flaw B, signal B will appear at a point on the time scale that is approximately halfway between the IP signal and the BW signal.

Since the IP signal corresponds to the front surface of the material, this indicates that flaw B is about halfway between the front and back surfaces of the sample.

When the transducer is moved over flaw C, signal C will appear earlier in time since the sound travel path is shorter and signal B will disappear since sound will no longer be reflecting from it.

B-Scan Presentation

The B-scan presentations is a profile (cross-sectional) view of the test specimen. In the B-scan, the time-of-flight (travel time) of the sound energy is displayed along the vertical axis and the linear position of the transducer is displayed along the horizontal axis.

From the B-scan, the depth of the reflector and its approximate linear dimensions in the scan direction can be determined.

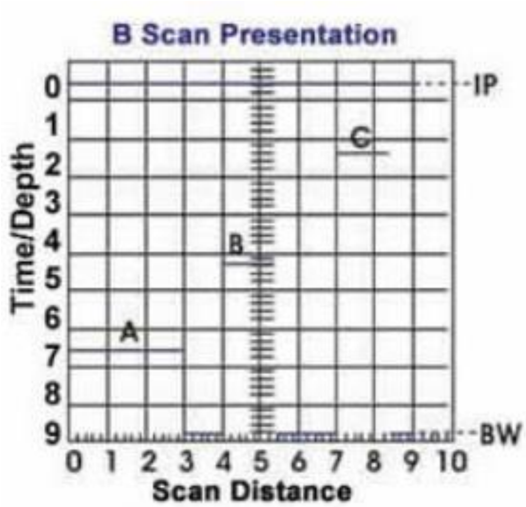

Figure. B-Scan Presentation

The B-scan is typically produced by establishing a trigger gate on the A-scan. Whenever the signal intensity is great enough to trigger the gate, a point is produced on the B-scan. The gate is triggered by the sound reflecting from the backwall of the specimen and by smaller reflectors within the material. In the B-scan image above, line A is produced as the transducer is scanned over the reduced thickness portion of the specimen. When the transducer moves to the right of this section, the backwall line BW is produced. When the transducer is over flaws B and C, lines that are similar to the length of the flaws and at similar depths within the material are drawn on the B-scan. It should be noted that a limitation to this display technique is that reflectors may be masked by larger reflectors near the surface.

C-Scan Presentation

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.

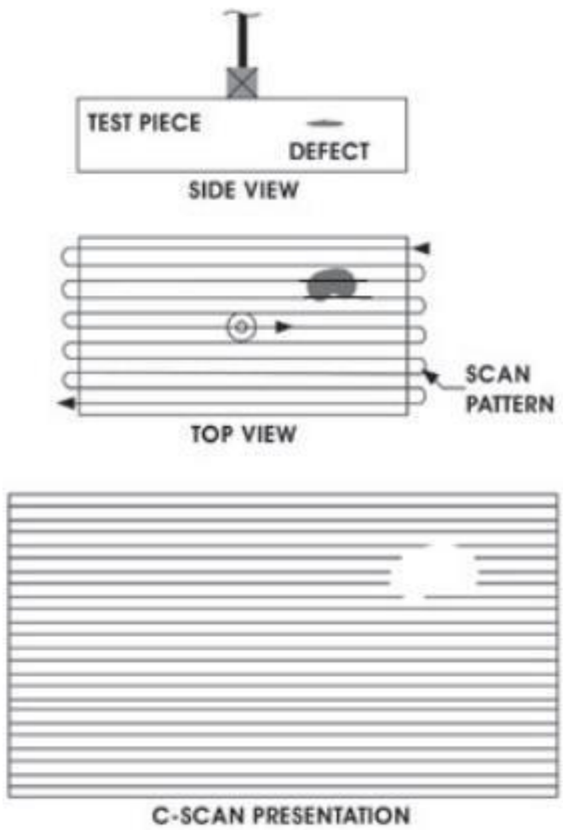

Figure. C-Scan Presentation

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.

ADVANTAGES AND LIMITATIONS of UT:

It is a matter of selecting the test method that offers the most effective approach to solving the examination problem. When determining whether ultrasonic is the most appropriate test method, consideration should be given to the following:

1. Part and geometry to be examined
2. Material type
3. Material thickness
4. Material process—cast, wrought, etc.

5. Type of discontinuities to be detected
6. Minimum discontinuity size to be detected
7. Location of the discontinuities—surface-breaking or internal
8. Orientation of discontinuities (very important when selecting a test technique)
9. Accessibility to areas of interest
10. Surface conditions
11. Type of examination record required

Ultrasonic inspection is ideal for locating small, tight discontinuities assuming the following:

1. The sound energy can be projected at some angle that will respond favorably to the orientation of the reflector.
2. The relationship between the size of the discontinuity and the material's grain structure allows for an acceptable signal to noise ratio.
3. The surface condition is suitable for scanning. A poor scanning surface will not only require a more viscous couplant but possibly the use of a lower test frequency. This may not provide the necessary resolution for the test.

The advantages of ultrasonic examination are as follows:

1. Inspection can be accomplished from one surface
2. Small discontinuities can be detected
3. Considerable control over test variables
4. Varieties of techniques are available using diverse wave modes
5. High-temperature examination is possible with the correct equipment
6. Examination of thick or long parts
7. Inspection of buried parts, e.g., shafts in captivated bearing houses
8. Accurate sizing techniques for surface-breaking and internal discontinuities is possible
9. Discontinuity depth information
10. Surface and subsurface discontinuities can be detected
11. High speed scanning is possible with electronic signal gating and alarm system
12. "Go/No-Go" testing of production components
13. Test repeatability
14. Equipment is light and portable
15. Area evacuation of personnel is not necessary
16. Special licenses are not required as with radiation sources
17. Minimum number of consumables

Some of the limitations of ultrasonic examination are as follows:

1. Discontinuities that are oriented parallel with the beam energy will usually not be detected. Orientation of the discontinuity (reflector) is the most important factor in detecting discontinuities.
2. Discontinuities that are similar to or smaller than the material's grain structure may not be detected.
3. Thin sections may present resolution problems or require the implementation of special techniques.
4. Uneven scanning surfaces can reduce the effectiveness of the test.
5. Signals can be misinterpreted. This includes spurious signals from mode conversion or beam redirection, etc.
6. In general, this method requires a high level of skill and training.
7. Permanent record of the examination results is not typical. The records are limited to physical documentation rather than an actual reproduction of the test, e.g., as is possible with radiography.

Introduction to Acoustic Emission Testing:

Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material.

When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors.

With the right equipment and setup, motions on the order of picometers (10 -12 m) can be identified. Sources of AE vary from natural events like earthquakes and rockbursts to the initiation and growth of cracks, slip and dislocation movements, melting, twinning, and phase transformations in metals.

In composites, matrix cracking and fiber breakage and debonding contribute to acoustic emissions. AE's have also been measured and recorded in polymers, wood, and concrete, among other materials.

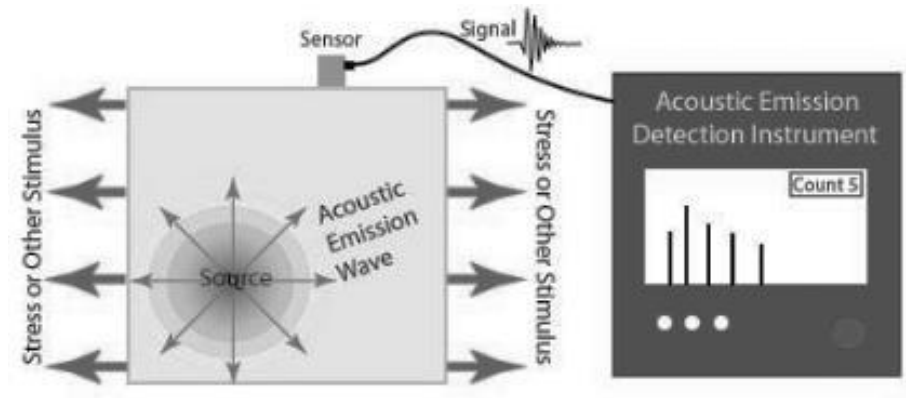

Figure. Acoustic Emission Testing

The AE Process Chain:

A process chain always exists at AE testing. The process chain basically consists of the following links:

1. Test object and application of load: Produce mechanical tensions
2. Source mechanisms: Release elastic energy
3. Wave propagation: From the source to the sensor
4. Sensors: Converting a mechanical wave into an electrical AE signal
5. Acquisition of measurement data: Converting the electrical AE signal into an electronic data set
6. Display of measurement data: Plotting the recorded data into diagrams
7. Evaluation of the display: From diagrams to a safety-relevant interpretation

As can be seen in figure below, mechanical stress has to be produced within the test object, which is usually done by applying external forces. The behavior of the material and the starting point of the release of elastic energy, e.g. by crack formation, are influenced by the material properties and the environment conditions.

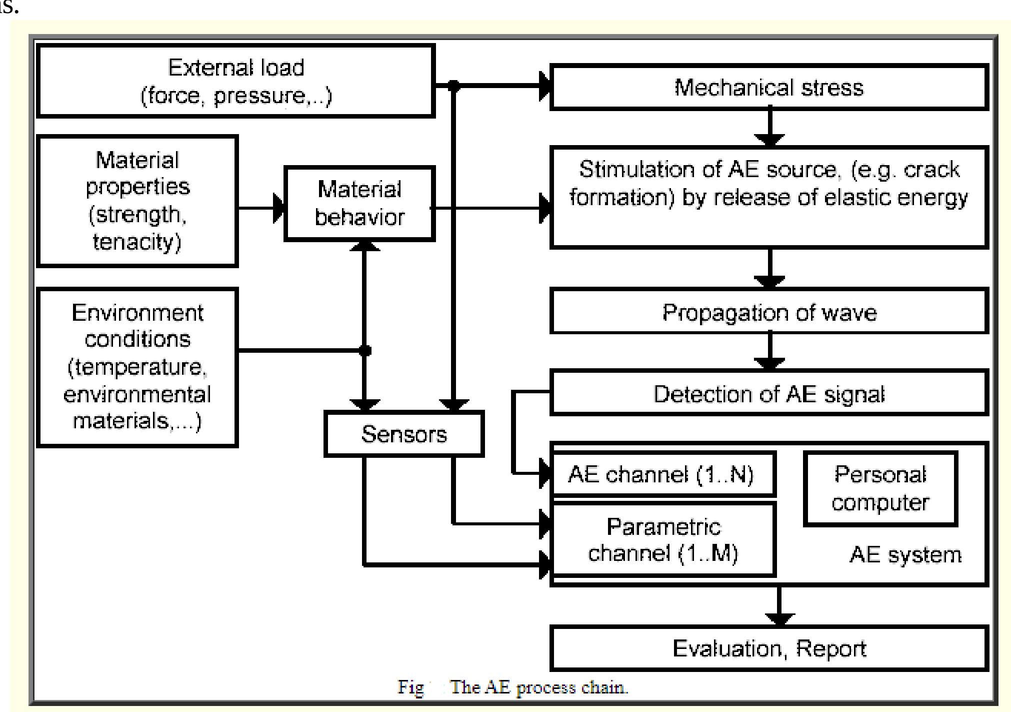

Figure AE Process chain

The elastic wave propagating through the material is detected and converted into the electrical AE signal by the AE sensors. The AE System processes the AE signal, converts the received wave packets into feature data sets, determines the source locations, calculates statistics, and displays them graphically and numerically. So-called parametric channels measure the environmental conditions as well as the external load as reference parameters for the detected AE.

AE Signal:

- ✓ Basically, there are two types of AE signals, transient and continuous signals.
- ✓ With transient AE signals, also called bursts, start and end points deviate clearly from background noise.

- ✓ With continuous AE signals, we can see amplitude and frequency variations but the signal never ends. In figure below, an example of both types of AE signals are shown.

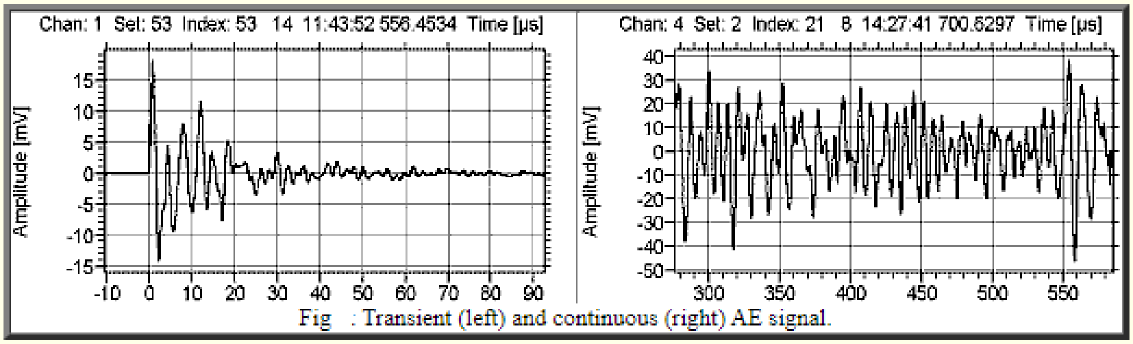

Figure. Transient (left) and continuous (right) AE signal

- ✓ The useful signals for AE testing at large pressure vessels are burst type signals, e.g. originating from fracture or crack growth. Continuous signals are mostly unwanted (noise) signals such as friction or flow noise.
- ✓ But even burst signals can be interfering signals, e.g. short friction noise or electrical spikes. At the best the background noise is just the electronic noise of the preamplifier or the sensor.

AE Parameters

In very few cases, AE testing is based on only a few bursts. In general, some hundreds or thousands of bursts are recorded for statistic evaluation. Statistical evaluation of waveforms themselves is difficult, but certain features of waveforms can be evaluated statistically. One has to determine the most important parameters of each waveform in order to compare the results of the structure under test with those of defect-free test object and with those of a defective test object. The most commonly used features are shown in figure below

- ✓ Arrival time (absolute time of first threshold crossing)
- ✓ Peak amplitude
- ✓ Rise-time (time interval between first threshold crossing and peak amplitude)
- ✓ Signal duration (time interval between first and last threshold crossing)
- ✓ Number of threshold crossings (counts) of the threshold of one polarity
- ✓ Energy (integral of squared (or absolute) amplitude over time of signal duration)
- ✓ RMS (root mean square) of the continuous background noise (before the burst)

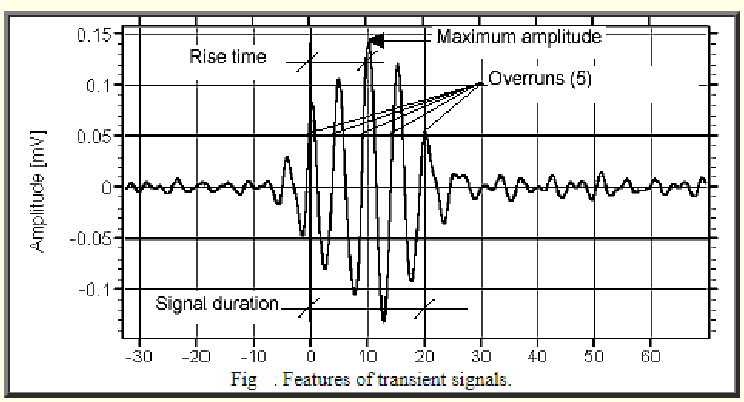

Figure. Features of transient signals

AE bursts are not only produced by the defects we are looking for but can also originate from drop- ins such as peak values of the background noise, which sometimes exceed a low threshold. Therefore, it is very important to determine those characteristics that distinguish the wanted from the unwanted bursts.

The peak amplitude is one of the most important burst features. Crack signals show medium to high amplitudes and have durations of some 10 μ s, depending on the test object's properties.

In most cases, bursts with less than 3 threshold crossings and durations less than 3 μ s can be regarded as unwanted signals. Most of the bursts with low amplitudes and long duration are friction noise.

Very short signals may indicate electrical noise peaks, especially, if they arrive at all channels at the same time. With logical filters one can separate bursts on the basis of those burst features in a flexible way. This must be done carefully: Always make sure not to miss inadvertently important bursts.

What are the Advantages and Limitations?

Acoustic emission has many advantages over other methods. These include:

- ✓ Ability to detect a range of damage mechanisms including, but not limited to, fibre breakages, friction, impacts, cracking, delamination and corrosion in their early stages, before they become significant issues
- ✓ Can be conducted during operation, during qualification (proof) testing or development testing
- ✓ Can locate damage sources and can be differentiate these based on acoustic signatures
- ✓ Global monitoring of a structure
- ✓ Assesses the structure or machine under real operational conditions
- ✓ A non-invasive method
- ✓ Operational in hazardous environments, including high temperatures, high pressures and corrosive and nuclear environments
- ✓ Can be conducted remotely
- ✓ Can detect damages in defects that are difficult to access with conventional non-destructive testing techniques

However, the method does also have some limitations:

- ✓ Limited to assessing structural integrity or machine health by locating issues, further inspection is usually required to fully diagnose issues
- ✓ Cannot detect defects that may be present, but that do not move or grow
- ✓ Can be slower than other non-destructive testing techniques

Applications

Acoustic emission can be applied to a range of applications and materials. These include:

1. Structures

- ✓ Concrete structures such as bridges and buildings
- ✓ Metallic structures such as pressure vessels, pipelines, storage tanks, aircraft structures and steel cables
- ✓ Composite structures such as aircraft structures, motorsport structures and composite beams

2. Machines

- ✓ Rotating machinery such as detecting early wear in bearings and gearboxes
- ✓ Electrical machinery such as detecting partial discharge in transformers and bushings

3. Processes

- ✓ Additive manufacturing for assessing build quality during build
- ✓ Leak detection in pipelines and pressure systems
- ✓ Particle impacts
- ✓ Frictional processes