Chapter: 1

Introduction of Non-Destructive Testing (NDT)

1.1- Introduction of NDT:

The inspection of metal structures such as oil and gas pipelines, rail tracks, automobile components, welded joints and bridges or metal components in manufacturing etc is a common requirement in industry, so there is a need for fast, reliable and cost effective surface and sub-surface defect detection systems for inspection of materials. Flaws can affect serviceability of the material or structure, so NDT is important for safe operation as well as for quality control and accessing plant life. The flaws may be cracks or inclusions in welds and castings, or variation in structural properties which can lead to loss of strength or failure in service.

Non-destructive Testing (NDT) is the examination of an object or material for detecting and evaluating flaws in materials with technology that does not affect its future usefulness. NDT can be used without destroying or damaging a product or material. Because it allows inspection without interfering with a product's final use, NDT provides an excellent balance between quality control and cost-effectiveness. Commonly used inspection techniques include visual inspection, liquid penetrant testing, ultrasonic inspection, eddy current testing and magnetic flux leakage testing, magnetic particle testing [1].

1.2- Objective of NDT:

The object of NDT is to find flaws in the material being tested, and the successful application of the test is largely dependent upon the skill of the operator and the equipment used. The objective of each test method is to provide information about the following material parameters [1]-

- Discontinuities and flaw
- Structure
- Dimensions and metrology
- Physical and mechanical properties
- Composition and chemical analysis

1.3-Purpose of NDT:

Since the 1920s, nondestructive testing has developed from a laboratory curiosity to an indispensable tool of production. No longer is visual examination the principal means of determining quality. Nondestructive tests in great variety are in worldwide use to detect variations in structure, minute changes in surface finish, the presence of cracks or other physical discontinuities, to measure the thickness of materials and coatings and to determine other characteristics of industrial products [1]. Modern nondestructive tests are used by manufacturers-

- To ensure product integrity, and in turn, reliability
- To avoid failures, prevent accidents and save human life.
- To ensure customer satisfaction and maintain the manufacturer's reputation.
- To aid in better product design.
- To control manufacturing processes.
- To lower manufacturing costs.
- To maintain uniform quality level.

1.4- Rapid Growth and Acceptance of NDT:

The whole area of nondestructive testing (NDT) is currently undergoing a period of rapid change brought about by a combination of technological, regulatory and economic factors worldwide. The driving forces; for changes in NDT practices include the introduction of new materials and manufacturing processes, advancement in the inspection technologies themselves, increasing pressures for cost-effectiveness and quality in production, and the need to extend the life of ageing infrastructure. Rapid Growth and Acceptance of Non-Destructive Testing takes place because of [1]-

- Increased Complexity of Modern Machinery
- Increased Demand on Machines
- Engineering Demands for Sounder Materials
- Public Demands for Greater Safety
- Rising Costs of Failure

1.5- NDT Technology Selection:

Selecting the appropriate technique for a particular application requires care and understanding since all NDT techniques have limitations that must be well understood to ensure the desired reliability of inspections. The selection of NDT technology depends on many variables; some of them are [1] -

- Examination objectives
- NDT technology capabilities & limitations
- NDT technology cost
- Orientation and accessibility of the test piece
- Test piece geometry and size
- Internal variables in densities of the material
- Possible location and orientation of discontinuities

1.6- Application of NDT:

NDT is used in a variety of settings that covers a wide range of industrial activity. NDT are applied not only in engineering but also in medical fields. The various industries in which non-destructive testing used are-

- Automotive industry- for testing engine parts and frame etc.
- Aerospace industry - -for testing air frames, rocket engine parts etc.
- Powerplant industry- for testing propellers, reciprocating engines, gas turbine engines, boilers, heat exchangers etc.
- Construction industry- for testing of structures, bridges etc.
- Manufacturing industry- for testing of cast products, forged products, welded joints etc.
- Petroleum and Gas industry- for testing of pipelines, oil storage tanks, pressure vessels etc.
- Railways- for rail inspection, wheel inspection, frame etc.
- Medical imaging applications.

1.7- Common NDT Methods:

Visual Testing: Visual inspection is the simplest, fastest, economical and most commonly used test for detecting defects on the surfaces of the welded objects. The weld surface and joint is examined visually, preferably with the help of a magnifying lens. Careful examination of what can be seen on the surface of a welded joint can assist in determining the ultimate acceptability of the weldments. Visual examination can help detecting the following flaws on the surface of the welded structure. It is least expensive of the various inspection methods, requires the least investment in tools and equipments and usually requires least time.

Dye Penetrant Testing: A liquid penetrant test is non-destructive type. It detects flaws that are open to the surface e.g., cracks, seams, laps, lack of bond, porosity, cold shuts, etc. It can be effectively used not only in the inspection of ferrous metals but is especially useful for non-ferrous metal products and on non-porous, non-metallic materials such as ceramics, plastics and glass.

The basic principle of liquid penetrant test is that the liquids used for testing enters small openings such as cracks or porosities by capillary action. The rate and extent of this action are dependent upon such properties as surface tension, cohesion, adhesion and viscosity. After a period of time called the "dwell," excess surface penetrant is removed and a developer applied. This acts as a blotter. It draws the penetrant from the flaw to show its presence.

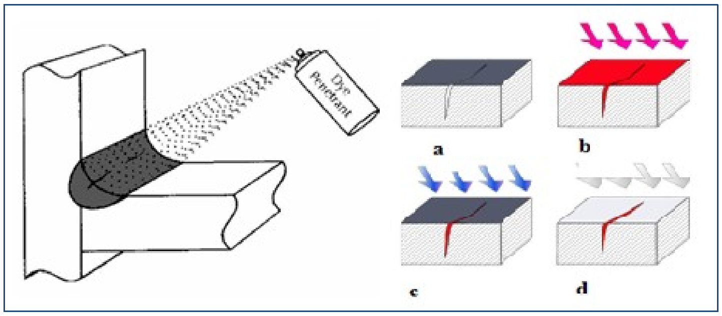


Figure 1.7a, Dye Penetrant Testing [2]
(a) Section of material with a surface crack (b) Penetrant is applied.
(c) Excess penetrant is removed (d) Developer is applied, rendering the crack visible.

The test sensitivity depends upon the type of materials that are used in the test stages and the characteristics of defects and test materials. Capillary action is important in those processes. For example; the penetration time ensures adequate time for capillarity action in the surface discontinuities, and sensitive effects of penetrants, pre-cleaning materials or developers as a function of their capillarity properties.

Magnetic Particle Testing: Magnetic particle inspection will indicate surface or near-surface defects in ferromagnetic materials such as iron and steel. A magnetic current is introduced into the area to be inspected, and iron oxide powder is dusted on the area. The induced magnetic field will be distorted if there is a discontinuity such as a crack on or near the surface. A leakage of this field creates local magnetic poles at flaw edges that attract the iron oxide powder dusted on the area. A sharp line indicates a surface discontinuity. When the discontinuity is below the surface, the field is weaker and less concentrated; therefore, the powder indication on the surface will be broad and fuzzy.

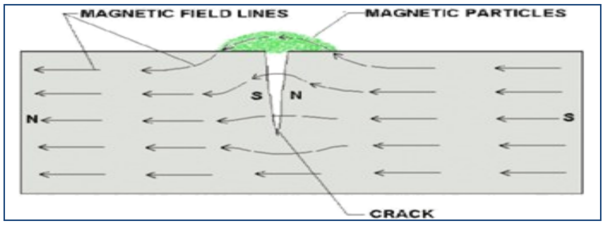


Figure 1.7b, Magnetic Particle Testing [3]

The advantages of magnetic particle inspection are that it is a positive method of finding all cracks at the surface, the equipment is portable, and the method is fast and flexible. A principal limitation of the magnetic particle method is that it applies only to magnetic materials and is not suited for small deep-seated defects. The deeper the defect is below the surface, the larger it must be to be detected. With magnetic particle testing, the surface to be inspected must be accessible.

This means shafts or other equipment cannot be inspected without removing pressed wheels, pulleys, or bearing housing.

Eddy Current Testing: Eddy current inspection is used in a variety of industries to find defects and make measurements. One of the primary uses of eddy current testing is for defect detection when the nature of the defect is well understood. In general, the technique is used to inspect a relatively small area and the probe design and test parameters must be established with a good understanding of the flaw that is to be detected. Since eddy currents tend to concentrate at the surface of a material, they can only be used to detect surface and near surface defects.

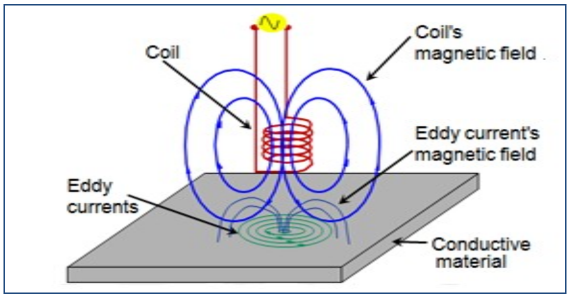


Figure1.7c, Eddy Current Testing [4]

Eddy current testing method utilizes the principle of electromagnetism. In eddy current testing, an alternating current is passed through a coil placed in the proximity of the electrically conducting material. The changing current in the coil creates an alternating magnetic field in the component material. The varying magnetic field in the component generates eddy currents in the material to be tested. Thus eddy currents are a form of induced currents. These eddy currents, which vary with the magnetic field, create their own magnetic field which interacts with the initial field. The magnitude and phase of the eddy currents will affect the loading on the coil and thus its impedance. Defects such as cracks are detected when they disrupt the path of eddy currents and weaken their strength. This is the basis of eddy current testing.

Radiographic Testing (RT): Radiography is a method of NDT which involves the use of penetrating gamma- or X-rays to examine materials and product's defects and internal features by the resulting image on a recording film or a viewing screen. Radiation is directed through a part and onto a recording film or other media. The resulting shadowgraph shows the internal features and soundness of the part.

The basic principle of radiographic testing is based on the differential absorption of penetrating electromagnetic radiation by the metal being tested due to non-uniformity in its structure such as defects, variation in thickness, composition etc. As the electromagnetic radiation is applied, some part of the radiation is absorbed by the material and remaining is transmitted to the recording film. When transmitted radiation impinges on the recording film, a photochemical change takes place. The amount of photochemical change is directly proportional to the intensity of the radiation and the duration of the exposure to the radiation. Thus due to differential absorption of the penetrating radiation in the material, different areas on the recording film are exposed differently.

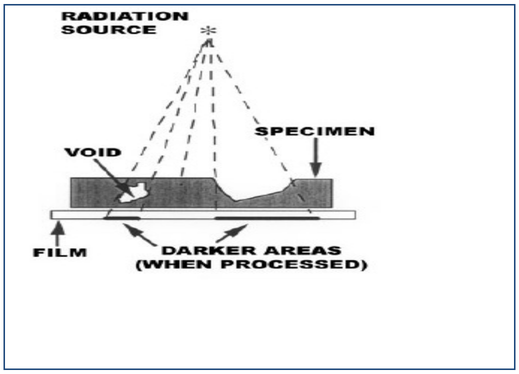


Figure 1.7d, Radiography Testing [5]

The choice of which type of radiation is used (x ray or gamma) depends on the thickness of the material to be tested. Since gamma rays having high penetrating power, so they are used for testing thicker metals. The thickness of steel which can be inspected depends on the incident X-ray energy.

Ultrasonic Testing: Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. In this method a beam of ultrasonic waves is directed into the object to detect and locate internal defects or discontinuities. When the ultrasonic waves are directed into the object, they reflected not only at the interfaces but also by internal flaws. A receiver probe picks up the reflected ultrasonic wave and an analysis of this signal is done to locate flaws in the object under inspection. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization etc.

Chapter: 2

Literature Review

Ultrasonic nondestructive testing is most widely used technique for detection and characterization of internal and sub-surface defects in weld joint. Many researchers and academicians of international repute had did lot of work for detection and characterization of defects in weld joint by ultrasonic testing whose name and work abstract has been given below:

- Sony Baby, T. Balasubramanian, R.J. Pardikar [6] studied the sizing of embedded vertical cracks in ferritic steel welds using ultrasonic techniques based on transit time. They using two technique for sizing a embedded crack (ì) flaw tip echo method and (ìì) mode conversion method. In flaw tip echo method, an ultrasonic beam is directed with an angle to a defect, an echo is obtained from the defect edge. In this method, the height of the defect is determined geometrically from the beam path distance at the position where the peak value of echo is obtained from the end of the defect and the angle of refraction of the probe used. In mode conversion method, when the shear wave generated from the angle probe impinges on the crack like defect, some of the shear waves are reflected directly at the upper tip of the defect and travel back to the probe. At the same time some of the shear waves are mode converted to surface wave and propagated along both side of the defect. When the mode converted surface waves come down to the lower tip of the defect, some of them are reflected and some of them are bent around the tip. These surface waves are propagated along the defect and at the upper tip of the defect get reconverted to the shear wave and travel back to the probe. In this method, the height of the crack like defect can be calculated as $h = (CR/CS) \times \Delta x$, where CS and CR the velocity of the surface wave and the shear wave and Δx is the difference in the echo position of the surface wave and the shear wave. Using both the techniques excellent agreement was obtained between the estimated crack height and actual crack height.

- Ichiro Komura, Taiji Hirasawa, Satoshi Nagai, Jun-ichi Takabayashi and Katsuhiko Naruse [7] studied the crack detection and sizing by ultrasonic water gap phase array technique for an inspection of the core shroud of the BWR internal component in nuclear power plant. In this technique they used newly developed 256- channel array probe. In this, the defect-detection and sizing capabilities have been examined on the specimens that had EDM slots. The probe has been setup over the weldment with the water gap 15mm. simultaneous B- scan imaging for three different directions carried out. The difference of three B-scan images from different beam direction is observed. Thus, it has been shown that the inspection results from different beam direction by phased array system are useful in obtaining the correct information about the size and shape of the flaw.

- M. Arone, D. Cerniglia, V. Nigrelli [8] has studied the defect characterization in Al welded joints by non-contact Lamb wave technique. Inspection of aluminum welded joints was carried out using two techniques to obtain a quantitative result. The first, completely non-contact using a laser source and an air-coupled receiver and the second, with contact angle-beam probe as source and air-coupled receiver, permitted quick selection of proper Lamb wave mode to quantify the defects in the joint. Lamb waves allow inspection of the complete thickness with only one scan, permitting to detect and to size both internal and surface defects. The inspection of the whole welded joint was performed, and using the Wavelet transform the presence and the sharp position of the defects were determined. Experimental test was performed to evaluate how much a misalignment of the sensor affects signal amplitude. Another test was directed to determine the opportune distance between source and receiver that is the maximum length that can be inspected with still a good signal to noise ratio.

- R.S. Edwards, S. Dixon, X. Jian [9] studied the characterization of defects in the railhead using ultrasonic surface waves. They using pitch catch ultrasonic testing technique and electromagnetic acoustic transducer to detect and characterize the defects in railhead. The depth of the defects is characterized through analysis of both the time domain signal amplitude and frequency dependent behaviour. Depth gauging of defects is possible by looking at changes in the signal amplitude and frequency content as the EMATs are scanned along a sample. When the EMATs are on either side of a defect a portion of the signal dependent on the depth of the crack and the ultrasonic wavelength will be reflected back towards the generator and a portion will be transmitted under the crack and detected. For signals with wavelength longer than the crack depth, a larger fraction of the surface wave energy will be able to pass under the crack, increasing with wavelength. Signals with wavelengths shorter than the crack depth will effectively be blocked. By looking at the change in amplitude and frequency content of the signal and comparing these to a known calibration the depths of defects can be measured.

- Tianlu Chen, Peiwen Que, Oi Zhang, and Qingkun Liu [10] studied the signal identification technique based on the empirical mode decomposition (EMD) of ultrasonic signals for sizing and locating a flaw. This signal identification technique is used to improve the arrival time resolution of diffracted wave’s signals from a flaw. The ultrasonic signals are decomposed into several intrinsic mode functions by empirical mode decomposition. Some modes are selected to reconstruct a new signal considering their frequencies and energy. The reconstructed signal has a better signal-to noise ratio and enhanced flaw information. A Hilbert transform is conducted to get the envelope and exact arrival time of the signal.

- R. Bullough, R.E. Dolby, D.W. Beardsmore, F.M. Burdekin, C.R.A. Schneider [11] studied the probability of formation and detection of large flaws in welds in nuclear components. They studied, four potential flaw formation mechanisms (i) lack of fusion, (ii) weld metal solidification cracking, (iii) hydrogen-induced cracking in the heat-affected zone, and (iv) hydrogen-induced cracking in the weld metal by Wilson model. The distribution of large flaws remaining after pre-service inspection is calculated for each mechanism as the product of the probability of forming the flaw and the probability of the flaw being undetected.

- Seung-Kyu PARK, Yong-Moo CHEONG, Sung-Hoon BAIK, Hyung-Ki CHA, Sung-Hoon LEE and Young-June KANG [12] studied surface-breaking crack depth by using the surface waves of multiple laser beams. A laser ultrasonic system is a non-contact inspection device with a long stand-off distance. They uses multiple surface waves generated by line-shaped multiple pulse laser beams to precisely detect a surface-breaking crack with its depth information. When a surface crack is positioned at the center of multiple pulse laser beams, acquired surface waves are composed of two parts, a reference part and a data part. The reference part is the front part of the acquired multiple surface waves and the data part is the rear part of the surface waves. A crack advent can be detected by a real-time monitoring of a signal variation in the time domain and frequency domain. The crack depth information can be extracted by acquiring the difference values between two peak frequencies in the reference signal and in the data signal.

- M. Riahi and M. R. Abolhasany [13] studied the Time-of-Flight Diffraction Technique for nondestructive testing of welds and thick layers of steel. TOFD is based on measurement of the time of flight of the ultrasonic waves diffracted from the tips of discontinuities (defects). In this technique, diffracted signals and their time of arrival from the tip of a defect is measured. In the TOFD technique the transmitting and receiving probes are located equidistant over the weld centre and scanned parallel with the weld. A transmitting probe emits a short burst of sound into a material, and this energy spreads out and propagates in an angular beam. Some of the energy is reflected from the flaw, and some is incident to the flaw and is diffracted away. A fraction of this diffracted sound travels toward a receiving probe. The receiving probe receives this diffracted sound energy and displayed on CRT. In this technique four signals are used to characterize a defect (1) the signal of the under-skin wave, (2) the diffracted signal of the wave from the top of the defect, (3) the diffracted signal of the wave from the bottom of the defect and, (4) the signal of the wave from the back wall. The depth of scattering, as well as a defect's location and size, can be calculated on the basis of a simplified triangle constructed from data on the time of arrival of signals.

- E. G. Bazulin [14] studied the Synthetic Aperture Focusing Technique for imaging of flaws with allowance for multiple reflections of ultrasonic pulses from plane- parallel boundaries of a test object. In this technique, a single element transducer acts as an active element for both transmission and reception. The focusing operation is done only in the reception mode and does not take into consideration the beam pattern during transmission. The transmission produces a highly divergent beam. The SAFT algorithm works as follows: The peak value in the A-scan under consideration is assumed to indicate the position of the defect. Hence, all the remaining A-scans within the aperture are time shifted accordingly and added with the current A-scan and averaged. This is called the delay and sum operation and results in a new spatially averaged A-scan. The procedure is repeated for the all the subsequent A-scans along the scan length. The advantage of using the delay and sum operation is that if the defect were actually present at that location indicated by the A-scan, the summing and averaging effect would result in constructive interference and hence a strong enhanced signal. On the contrary, if the defect were not present at that location indicated by the A-scan, it would result in destructive interference and his kill the false indication in the signal in the summing and averaging operation thereby increasing the SNR of the signal considerably. It was observed that SAFT significantly improves the lateral resolution of the B-scan and gave better defect definition with respect to its position and size.

- B. Messer, C. Patrick, and S. Seitz [15] studied the ultrasonic testing of weld joint by using phase array technique. Phased array ultrasonic inspection is an extension of conventional ultrasonic inspection and utilizes an array of piezoelectric elements rather than just one. The elements are contained in a signal probe; however, with computer controls the individual elements can be manipulated and coordinated to produce a focused ultrasonic beam with steering capabilities. With electronically controlled ultrasonic wave beams it is possible to detect defects in joints with complex geometry, thereby allowing complete volumetric inspection. Focusing of the beam also enhances space resolution with better sizing and mapping characteristics.

- Xiaoming JIAN, Steve DIXON, Karl QUIRK [16] studied the electromagnetic acoustic transducers (EMAT) for in-plane and out- of- plane ultrasonic wave detection. EMATs generate and detect ultrasonic waves via electromagnetic coupling between the EMAT and the metal samples. They operate via the Lorentz force or magnetostriction mechanisms or the use of both simultaneously. EMATs are non-contact devices, and therefore ultrasonic waves can be measured with minimal disturbance to the ultrasonic wave itself or to the material. The in-plane and out-of-plane components of the particle velocity of bulk waves (longitudinal and shear) are always in phase. However, the in-plane and out-of-plane particle velocities of guided waves such as Rayleigh waves or Lamb waves are not in phase. By arranging the static magnetic field of the magnet in the EMATs perpendicular to the surface of the test specimen, the EMATs pick up the in-plane particle velocity of incident ultrasonic waves. By arranging the static magnetic field parallel to the surface of the test specimen, the EMATs pick up the out-of-plane particle velocity of incident ultrasonic waves. The defect response of an in-plane particle is different from the out-of-plane particle velocity where one may carry more information on the defect than the other for a specific inspection.

- Sung-Jin Song, Hak-Joon Kim and Hyeon Cho [17] studied an intelligent system for ultrasonic flaw classification in weldments which is called the Intelligent Ultrasonic Evaluation System. This intelligent system consisted of the following four ingredients: (1) a PC-based ultrasonic testing system; (2) an effective invariant ultrasonic flaw classification algorithm; (3) intelligent flaw classification software; and (4) a database with abundant experimental flaw signals. Once the intelligent ultrasonic evaluation system displays the captured ultrasonic testing signal, one needs to set the time gate to identify the flaw signal, and clicks the 'classifier' button. Then, the classification software runs automatically performing extraction of features and classification by the probabilistic neural network classifier. And finally, it reports the classification result in terms of the class-conditional posteriori probability with bar charts. For performing the flaw classification, the IUES extracts a set of features from the time domain waveform and the frequency domain spectrum.

- G. Baskarana, Krishnan Balasubramaniam and C. Lakshmana Rao [18] studied shear-wave time of flight diffraction technique for inspection and characterization of near-surface defects. In conventional time of flight diffraction technique longitudinal diffracted waves are used for detection and sizing of a flaw. When a longitudinal ultrasonic wave is incident on a crack-like defect, the wave is reflected, transmitted, and also diffracted at the edges. The diffracted energy spreads over a wide angle and can be picked up from almost anywhere along the surface of the structure. The defect sizing method based on the measurements of time difference between the diffracted signals from the crack tips. In shear wave TOFD, diffracted shear waves are used for detection and sizing of the defect. In TOFD four waves are used for sizing a defect, lateral wave, two diffracted waves at the top and bottom of the defect and, back wall wave. When an incident longitudinal wave front meets the defect, the wave diffracted as longitudinal-diffracted wave (L) and shear-diffracted wave (S). Since the shear wave velocity is smaller (half of longitudinal wave velocity), the longitudinal-diffracted wave reaches the receiver first followed by shear-diffracted wave. Thus longitudinal-diffracted echo always appear in between lateral and longitudinal back wall echo. When the inspection thickness decreases, the spacing between lateral wave and longitudinal backwall echo also decreases making the defect signal superposition themselves as well as with either of the reference echoes. Even though the spacing between two reference echo is less for thin section by making use of the shear-diffracted echoes provides additional information about the defect size because the spacing between longitudinal backwall and shear backwall is more (almost twice) than lateral wave and longitudinal backwall spacing.

- L. Satyanarayan, C. Sridhar, C.V. Krishnamurthy and Krishnan Balasubramaniam [19] studied simulation of ultrasonic phased array technique for imaging and sizing of defects using longitudinal waves and finite-difference time domain (FDTD) method. The FDTD model for the simulation and visualization of the elastic wave propagation is based on a first-order velocity–stress finite-difference method for homogeneous isotropic material. The equation of motion, the stress–strain relation together with constitutive equations, completely describes the elastic wave propagation in a homogenous material. The simulation results may be utilized in the design of experiments, optimal selection of experimental parameters such as the transducer frequency, depth of focus, angle of inspection, determination of focal laws and the interpretation of defect images.

- Borja LOPEZ [20] studied weld inspection with EMAT using guided waves. The shear wave is most commonly used for ultrasonic weld inspection. Shear Vertical and Shear Horizontal both have particle vibrations perpendicular to the wave direction. Conventional ultrasonic inspectional utilizes the shear vertical wave, with an angle of between 30° and 60° from the normal beam. Maintaining the position of the probe is critical to obtaining an accurate inspection. A limitation of shear vertical waves in weld inspection is the inability to cover the full vertical volume of the material. At some points defects may even limit complete inspection. On the other hand, shear horizontal energy can be extremely useful for weld inspection in two ways. 1-Shear horizontal waves do not mode convert (change direction, speed and motion) when striking surfaces that are parallel to the direction of polarization. This is especially relevant when examining austenitic welds and materials with dendritic grain structures (e.g. certain stainless steels). 2- At 90º shear horizontal energy becomes a guided wave that fills up the full volume of the material and permits inspection of the full cross-section of the weld.

- Gerhard Grün [21] studied basic principles of the welds inspection using the phased array ultrasonic method, inspection procedures and data analysis in welds using manual and semi-automatic S-scans and E-scans. Phased arrays can be electronically focused at short distances if they are appropriately programmed. This will generate a large angle beam at distances after the focal point. The E-Scan data interpretation is similar to the conventional ultrasonic manual testing, with the advantages of improved imagery and data recording. S-Scans offer other advantages because they use multiple angles and offer a larger coverage. The S-Scan image allows a fast defect evaluation.

- P. Kemnitz, U. Richter and H. Kluber [22] studied measurements of the acoustic field on austenitic welds by using electromagnetic probe. In nuclear power plants many of the welds in austenitic tubes have to be inspected by means of ultrasonic techniques. If component-identical test pieces are available, they are used to qualify the ultrasonic test technology. Acoustic field measurements on such test blocks give information whether the beam of the ultrasonic transducer reaches all critical parts of the weld region and which transducer type is best suited.

- G. A. Giller and L. Yu. Mogil'ner [23] studied the ultrasonic testing of welded joints in pipelines. The ultrasonic testing of welded joints in pipelines of small diameters (10 to 530 mm) with thin walls (2 to 10 mm) is carried out by using a chord transducer. These transducers operate at a high signal-to-noise ratio of no less than 20 dB for samples with implanted reflectors and no less than 12 dB for welded seams. They generate an acoustic field in a pipeline wall. The directivity parameters of this field enable an efficient detection of defects in a fused metal of a welded seam and provide a relatively low intensity of signals due to reflections from irregularities in enforcing beads of a seam.

- A. Lhe mery, P. Calmon, I. Lecoeur-Taıbi, R. Raillon, L. Paradis [24] studied modeling tools for ultrasonic inspection of welds. They studied how the metallurgical structure and associated elastic properties of weld affects the ultrasonic field by using finite difference and finite element methods. Elastic properties of weld materials are both anisotropic and heterogeneous. They are anisotropic because of the grain growth in the thermal directions during the solidification process, and heterogeneous due to the succession of welding layers constituted of disoriented grains. By using two modeling tools, they studied (i) effects of weld structure on ultrasonic field radiation; and (ii) effects of weld geometry on echo-structure from defects. Experimental evidence of beam deviation, deformation and scattering by the structure can be well predicted by calculating the field radiated by a transducer into the weld.

- F.W. Margrave, K. Rigas, D.A. Bradley, P. Barrowcliffe [25] studied the use of neural networks in ultrasonic flaw detection. Neural networks are based on models of biological neurons and form a parallel information processing array based on a network of interconnected elements. They using three types of neural network architectures, A 3-layered perceptron, A Self Organizing Map using Kohenen learning rule and, A 2-layered linear vector quantization network using a variant of Kohonen learning rule. By using these technique they find significant advantages in flaw detection and there classification.

Conclusions:

The conclusion of various research papers are as follow:

- Phase Array ultrasonic testing is best suited for detection and characterization of internal defects in thick weld joints.
- Time of Flight Diffraction technique gives good sizing of defects in thin weld joint.
- Ultrasonic testing with surface waves is suitable for detection surface and near to surface defects.
- Synthetic Aperture Focusing Technique improves the lateral resolution of the B-scan and gave better defect definition with respect to its position and size.
- Electromagnetic Acoustic Transducer is suitable for dry and non-contact ultrasonic testing.

Chapter: 3

Introduction of Ultrasonic Testing Technique

3.1- Introduction of Ultrasonic Testing:

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. In this method a beam of ultrasonic waves is directed into the object to detect and locate internal defects or discontinuities. When the ultrasonic waves are directed into the object, they reflected not only at the interfaces but also by internal flaws. A receiver probe picks up the reflected ultrasonic wave and an analysis of this signal is done to locate flaws in the object under inspection. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization etc.

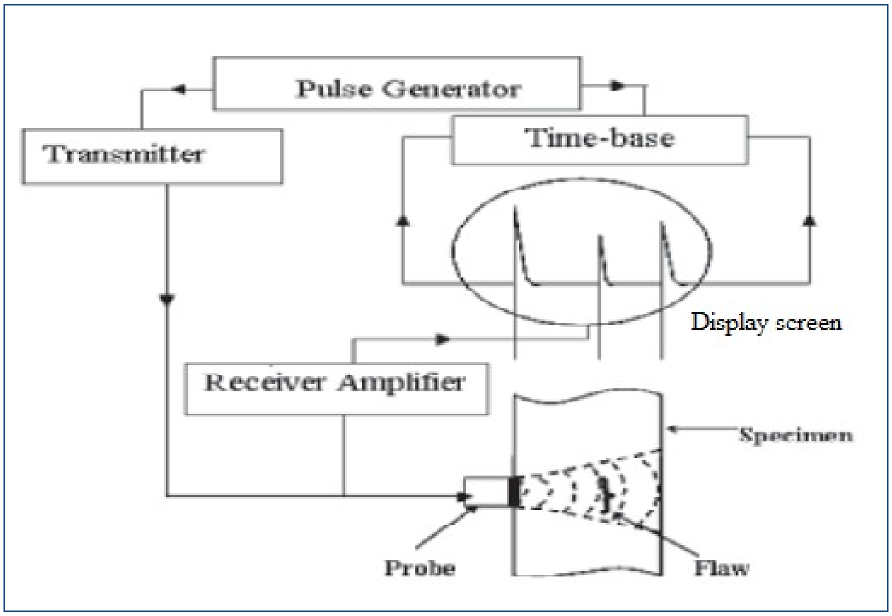


Figure 3.1 Ultrasonic Testing [26]

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. 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.

3.2- Principle of Ultrasonic Testing:

The basic principle of ultrasonic testing is based on the fact that solid materials are good conductors of sound waves. Sound travels through similar materials at constant velocities for a given sound wave length. Since different solid materials and fluids have different structural characteristics, leading to differences in acoustical properties. Because of difference in acoustic properties, sound travels at different speeds in different materials. Due to this reason, when the ultrasonic waves are directed into the object, they reflected not only at the interfaces but also by internal flaws (material separations, inclusions etc.).

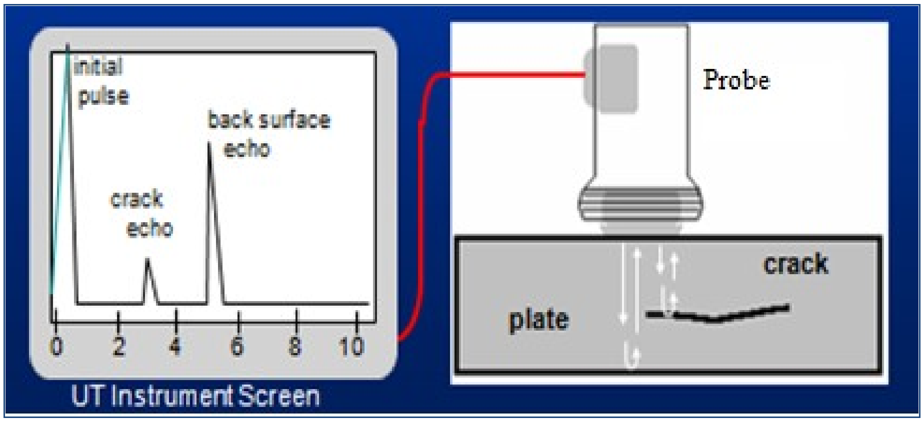


Figure 3.2 Principle of Ultrasonic Testing [1, 27]

When sound waves travel through a medium, a percentage of the sound energy is attenuated by either absorption or scattering. The remaining energy can be received and processed into an indicator of the material properties between the transmitter and receiver. A transducer is used for transmitting and receiving the ultrasound waves.

The interaction effect of sound waves with the material is stronger when wave length is small. This means that, for better detection of flaw the frequency of the ultrasonic waves must be high.

Due to this, ultrasonic waves with frequency range between about 0.5 MHz and 25 MHz are used. With lower frequencies, the interaction effect of the waves with internal flaws would be so small that detection becomes questionable.

Acoustic Impedance: The resistance offered to the propagation of an ultrasonic wave by a material is known as the acoustic impedance. The acoustic impedance (Z) of a material is the product of its density (ρ) and acoustic velocity (V).

$$Z = \rho V$$

The greater the impedance difference at a boundary, the greater the reflection that will occur, and therefore, the smaller the amount of energy that will be transferred.

3.3- Advantages 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.

3.4- Limitations of Ultrasonic Testing:

As with all NDT methods, ultrasonic inspection also has some limitations, which includes:

- 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.

3.5- Application of Ultrasonic Testing:

Generally, ultrasonic testing is applied for the following purpose:

- To detect defect.
- To measure the thickness of materials.
- To determine elastic modulus of materials.
- To study the metallurgical structure of materials

3.6- Present State of Ultrasonics Testing:

Ultrasonic testing has been practiced for many decades. Initial rapid developments in instrumentation spurred by the technological advances from the 1950's continue today. Through the 1980's and continuing through the present, computers have provided technicians with smaller and more rugged instruments with greater capabilities.

Many ultrasonic flaw detectors have a trigonometric function that allows for fast and accurate location determination of flaws when performing shear wave inspections. Cathode ray tubes, for the most part, have been replaced with LCD screens. These screens, in most cases, are extremely easy to view in a wide range of ambient lighting. Bright or low light working conditions encountered by technicians have little effect on the technician's ability to view the screen. Screens can be adjusted for brightness, contrast, and on some instruments even the color of the screen and signal can be selected. Transducers can be programmed with predetermined instrument settings. The operator only has to connect the transducer and the instrument will set variables such as frequency and probe drive.

Along with computers, motion control and robotics have contributed to the advancement of ultrasonic inspections. Computers can be programmed to inspect large, complex shaped components, with one or multiple transducers collecting information. Automated systems typically consisted of an immersion tank, scanning system, and recording system for a printout of the scan. The immersion tank can be replaced with a squirter system, which allows the sound to be transmitted through a water column. The resultant C-scan provides a plan or top view of the component. Scanning of components is considerably faster than contact hand scanning, the coupling is much more consistent.

Today, quantitative theories have been developed to describe the interaction of the interrogating fields with flaws. Models incorporating the results have been integrated with solid model descriptions of real-part geometries to simulate practical inspections. Related tools allow NDE to be considered during the design process on an equal footing with other failure-related engineering disciplines. The rapid advances in digitization and computing capabilities have totally changed the faces of many instruments and the type of algorithms that are used in processing the resulting data. High-resolution imaging systems and multiple measurement modalities for characterizing a flaw have emerged. Interest is increasing not only in detecting, characterizing, and sizing defects, but also in characterizing the materials. Goals range from the determination of fundamental microstructural characteristics such as grain size, porosity, and texture (preferred grain orientation), to material properties related to such failure mechanisms as fatigue, creep, and fracture toughness. As technology continues to advance, applications of ultrasound also advance. The high-resolution imaging systems in the laboratory today will be tools of the technician tomorrow [27].

3.7- Physics of Ultrasonic Testing:

3.7.1- Ultrasonic Waves:

Sound waves which have a frequency above the human hearing range are called ultrasonic waves. Ultrasonic waves are mechanical waves and consist of vibrations of the particles of the transmitting medium about their equilibrium positions. Ultrasonic waves can propagate in an elastic medium such as solid, liquid or gas but not in vacuum. Like a light beam, ultrasonic waves are reflected at surfaces and refracted when crossing an interface between two substances that have different acoustic properties. They also lose energy by scattering at rough surfaces. Ultrasonic Waves are characterized by the frequency, velocity, wavelength and, amplitude.

3.7.2- Characteristics of ultrasonic waves:

Ultrasonic waves behaves like light waves which having following characteristics-

- Freely propagates through not only liquids and gases but also solids.
- Reflect well at boundaries of internal flaws and other defects.
- Intense directivity and strong straight transmitting characteristics.
- Provides quick reciprocal conversion from/to electricity
- Suitable for real time processing
- Harmless to the human body
- Non-destructive in most applications.

3.7.3- Types of Ultrasonic Waves:

Ultrasonic waves are classified on the basis of the mode of the vibration of the particles of the medium with respect to the direction of propagation of the wave. The most commonly used waves in ultrasonic inspection are-

- Longitudinal or Compressional waves
- Transverse or Shear waves
- Surface waves
- Lamb or Plate waves

Longitudinal waves: These are sound waves in which the particles of the transmitting medium vibrate in the same direction as the propagation of the wave. The wave is propagated through the medium as a series of alternate compressions and rarefactions. Because of its easy generation and detection, this type of ultrasonic wave is most widely used in ultrasonic testing. Longitudinal waves have relatively high velocity and short wavelength. As a result energy can be focused into a sharp beam with minimum divergence. Longitudinal wave can propagate in solids, liquids and gases. The velocity of longitudinal ultrasonic waves is about 5900 m/sec in steel, 1500m/sec in water and 330m/sec in air.

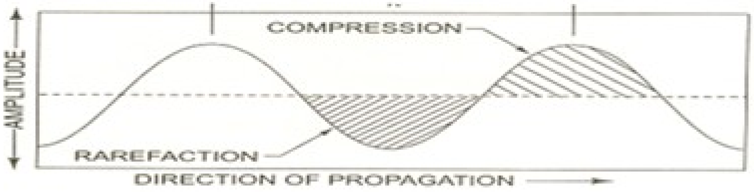


Figure 3.7.3a, Longitudinal Waves [27]

Transverse waves: These are sound waves in which the particles of the transmitting medium vibrate at right angles to the direction of wave propagation. The velocity of shear waves in a material is about 50% of the longitudinal waves in that medium.

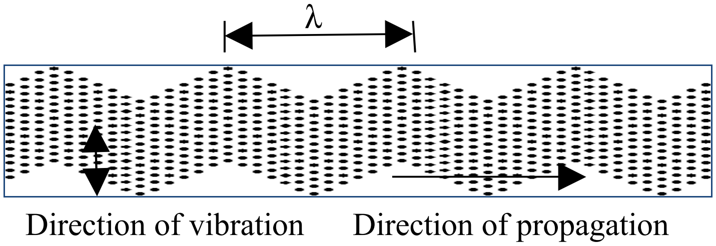


Figure 3.7.3b, Transverse Waves [27]

Transverse waves only propagate in solid materials never in liquids or gases because these do not have a shear modulus and therefore do not affect any shear forces.

Surface waves: These are another type of ultrasonic waves used in ultrasonic testing. These waves are propagated over the surface of a solid whose thickness perpendicular to the surface is large compared to the wavelength. The motion of the particles is both longitudinal and transverse. The region within which these waves propagate with effective energy is not much thicker than about one wavelength beneath the surface of the metal. These waves have a velocity approximately 90% of the transverse wave velocity in the same material. Surface waves are useful for testing purposes because the attenuation they suffer for a given material is lower than for an equivalent shear or longitudinal wave and because they can flow around corners and thus be used for testing quite complicated shapes. Only surface or near surface defects can be detected by using surface waves.

Lamb or Plate Waves: The plate waves are usually generated by the phenomenon of mode conversion when a sound beams impinging the plate obliquely from a relatively large transducer. Ultrasonic waves undergo multiple reflections and mode conversions within the metal like a plate. The resulting refraction and reflection at the interfaces produces many new signal packets. If the angle of incidence or the frequency of sound is adjusted properly, the reflected and refracted energy within the plate will constructively interfere, thereby generating the plate wave. Because these waves penetrate the entire thickness of the plate and propagate parallel to the surface, a large portion of the material can be interrogated from a single transducer location.

3.7.4- Properties of Ultrasonic Waves:

Ultrasonic waves having following properties-

- Reflection
- Refraction
- Mode conversions
- Critical angles
- Attenuation

Reflection of ultrasonic waves at a boundary: When ultrasonic waves travelling through one medium impinge on the boundary of a second medium a portion of the incident acoustic energy is reflected back from the boundary while the remaining energy is transmitted in to the second medium. Ultrasonic waves are reflected at boundaries because of difference in acoustic impedances 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. If the acoustic impedances of the two materials are equal, there will be no reflection.

Reflection coefficient: It can be defined as the ratio of reflected sound energy (Er) to the incident sound energy (Ei).

$$\text{Reflection coefficient} = \frac{Er}{Ei} = Rc = (Z_1 - Z_2)2/(Z_2 + Z_1)2$$

$$\text{Impedance mismatch} = \frac{Z_1}{Z_2}$$

Where Z_1 and Z_2 are the acoustic impedance of medium 1 and 2. The greater the difference in Z_1 and Z_2, the more the reflected portion and the less transmitted portion of the incident sound energy.

Transmission coefficient: It can be defined as the ratio of transmitted sound energy (E_t) to the incident sound energy.

$$\text{Transmission coefficient Tr} = \frac{Et}{Ei} = 1 - R$$

$$Tr = 4Z1Z2/(Z1 + Z2)2$$

For the metal/air boundaries commonly seen in ultrasonic flaw detection applications, the reflection coefficient approaches 100%. Virtually all of the sound energy is reflected from a crack or other discontinuity in the path of the wave. This is the fundamental principle that makes ultrasonic flaw detection possible.

Refraction of ultrasonic waves: When ultrasonic waves travelling through one medium impinge on the boundary of a second medium a portion of the incident acoustic energy is reflected back from the boundary while the remaining energy is transmitted in to the second medium. However, the transmitted wave undergoes an abrupt change in direction of propagation and this phenomenon is known as refraction. The phenomenon of refraction occurs only when the ultrasonic beam is incident obliquely to the interface (angle beam inspection).

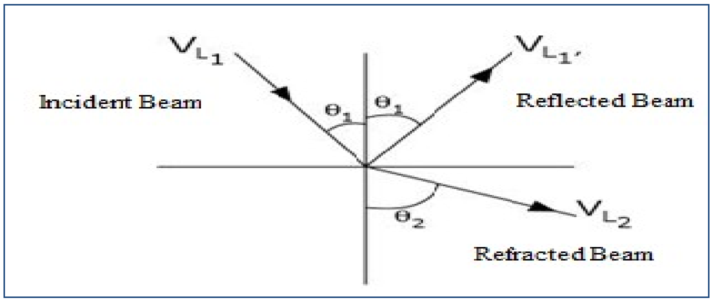


Figure 3.7.4a, Reflection and Refraction of Ultrasonic Waves [27]

When the ultrasonic beam is incident obliquely to the interface, the reflected wave is also at an angle to the surface. The relationship between incident beam angle and reflected beam angle can be given as

Angle of incident = Angle of reflection

But the angle of refraction is not equal to the angle of incident. The relationship between angle of incident and angle of refraction is given by the Snell's law.

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

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

Mode Conversion: Mode conversion means transformation of one kind of wave to another kind of wave. Due to mode conversion, a longitudinal wave partially converted in to shear waves and shear wave partially converted in to longitudinal waves. The phenomenon of mode conversion occurs when a beam of sound is introduced at an angle of incidence to the solid. It is observed in case of transmission of sound waves from one medium to another. This transformation occurs in both the reflected and transmitted waves. For small angles of incidence, mode conversions results in simultaneous propagation of longitudinal and shear waves with different velocities and in different directions in a second medium.

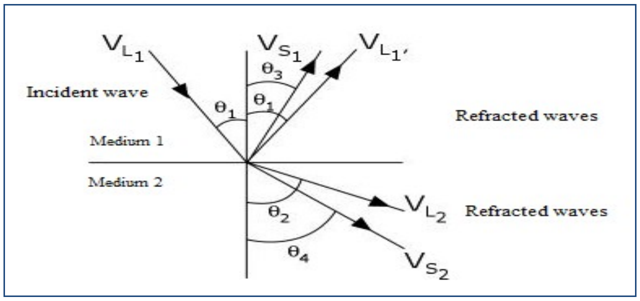


Figure 3.7.4b, Mode Conversion of Ultrasonic Waves [27]

The phenomenon of mode conversion depend on following parameters-

- The angle of incidence
- Acoustic impedances of the materials

- Velocity of the wave

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

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

Where: V_{L1} is the longitudinal wave velocity in material 1.V_{L2} is the longitudinal wave velocity in material 2. V_{S1} is the shear wave velocity in material 1. V_{S2} is the shear wave velocity in material 2. If, with angle beam scanning, this wave conversion is not taken into consideration, then location and evaluation of flaws is not possible in many cases, even detection becomes questionable because one echo on the display leads to two different flaw locations depending on whether one takes longitudinal waves or transverse waves as a basis as shown in fig.

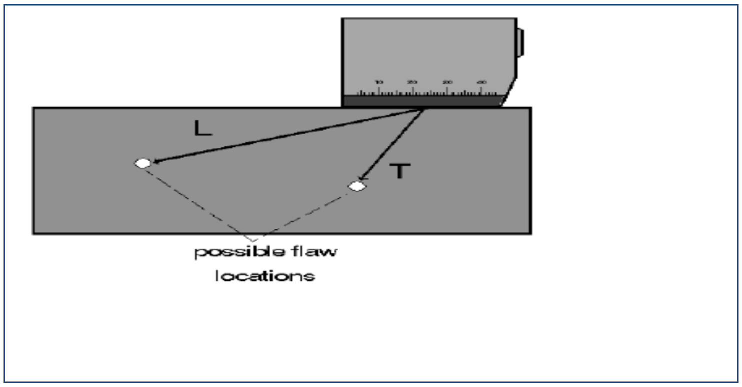


Figure 3.7.4c, Effect of Mode Conversion on Detectability of Flaw [28]

Since mode conversion will introduced two waves of different velocities and angles into the test material, the results will be confusing. Hence, it is required to eliminate one of them.

Critical angles: Critical angles are those incidence angle at which only one kind of sound wave (shear wave) is propagated into the material and another kind of wave is disappears, which is generated due to the phenomenon of mode conversion. The value of critical angles varies from material to material. When the longitudinal wave traveling in one medium is incident at an angle on the interface with the other medium, it undergoes refraction and mode conversion. The refracted angle of longitudinal and shear wave in other medium depends on the incident angle as well as the ratio of sound velocities in the two media (Snell's Law). Since the velocity of longitudinal waves is greater than the velocity of transverse waves, the refracted angle of longitudinal waves is always greater than that of transverse waves. Increase in the incidence angle results in increase in refracted angles of longitudinal and shear wave.

First critical angle: If the incident angle is increased, the refracted angles (of both refracted waves, longitudinal and shear waves) will also increases and at a particular incident angle the refracted angle of longitudinal wave will be 90 degrees. Under this condition, longitudinal waves disappear and only shear waves will be present in the second (refracting) medium. The corresponding incident angle is called the first critical angle.

Second critical angle: Beyond the first critical angle, a further increase of the incidence angle, refracted angle of shear wave will continue to increase and will reach 90 degrees. Under this condition, the refracted shear waves will also disappear from the second medium. The corresponding incidence angle is called second critical angle. At second critical angle, shear wave travelling at right angles to the normal (travelling along the surface).

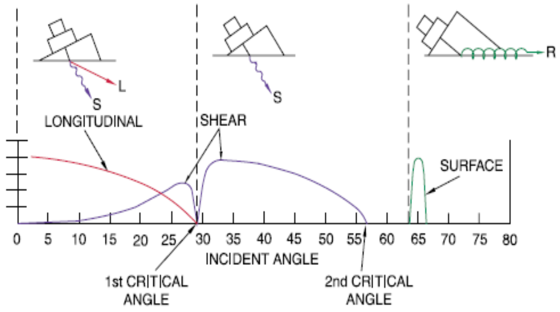


Figure 3.7.4d, 1st and 2nd Critical Angles

Thus for angle beam scanning, the incident angles should be between the first and second critical angles because-

- Below first critical angle, both the longitudinal and shear waves are propagated in the second medium.
- Between first and second critical angles, only shear wave is propagated in the second medium.
- Beyond the second critical angle, total reflection of shear wave starts and no more sound waves are transmitted into the second medium.

Usable range of angle probes: The area in which an angle of incidence is present between the 1st and 2nd critical angle (27.5° - 57°) gives us a clear evaluable sound wave in the test object (made of steel), namely the transverse wave between 33.3° and 90°. A 45° beam is the ideal one.

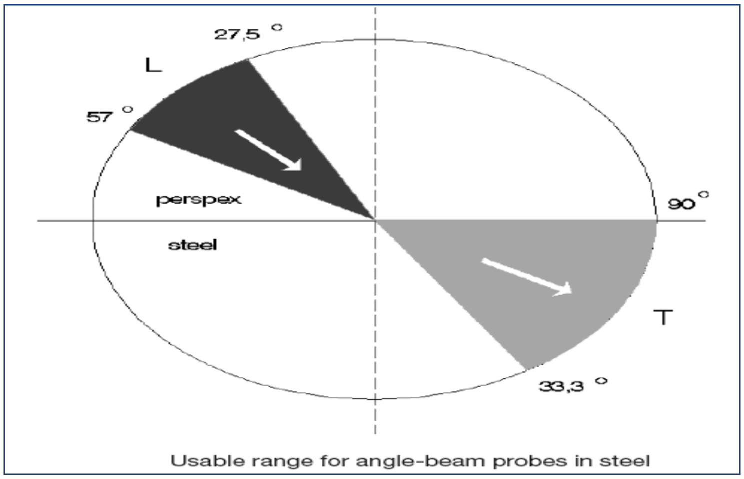


Figure 3.7.4e, Usable Range for Angle Beam Probe in Steel [28]

For Perspex/steel interface

First critical angle = 27.5° and corresponding refracted angle = 33.3°
Second critical angle = 57° and corresponding refracted angle = 90

Attenuation: Attenuation refers to the loss of sound energy as the ultrasonic beam passes through the material. Due to attenuation, the intensity of ultrasonic beam that is sensed by a receiving transducer is considerably less than the intensity of initial transmission. The attenuation is mainly due to the following reasons:

- Absorption
- Scattering

Absorption: Sound propagates through the vibration of particles of a solid, liquid or gases and the movement of those particles causes friction and absorbs some of the energy. The rate at which energy is absorbed depends on the material through which the sound is passing and the frequency of the sound.

Scattering: Scattering of Ultrasonic Waves result if the material is not strictly homogeneous. It contains boundaries on which the acoustic impedance changes abruptly because two materials of different density or sound velocity meet at these interfaces. The scattering of sound waves also depends on the grain size of the material. Very fine – grained materials causes very little scatter but coarse – grained material causes high scatter. The scattered energy that does not reach at transducer is lost energy. The sound attenuation:

- Increase with an increase in sound frequency.
- Depends upon the material (absorption is different for different materials).

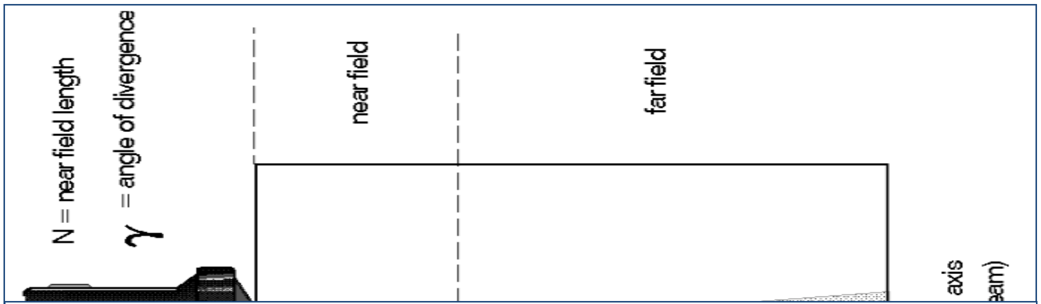
- Depends upon the metallurgical structure of the material (this affect scattering).

3.7.5- Characteristics of Ultrasonic Beam:

The sound that generate from a piezoelectric transducer does not originate from a point, but instead originates from most of the surface of the piezoelectric element. The region in which ultrasonic wave is propagated from a transducer is known as ultrasonic beam. Within the beam, the intensity or amplitude of the sound energy varies with distance from the transducer. A sound beam can be roughly divided into two regions-

- Near field (convergent or focusing area)
- Far field (divergent or spreading area)

- Beam spread



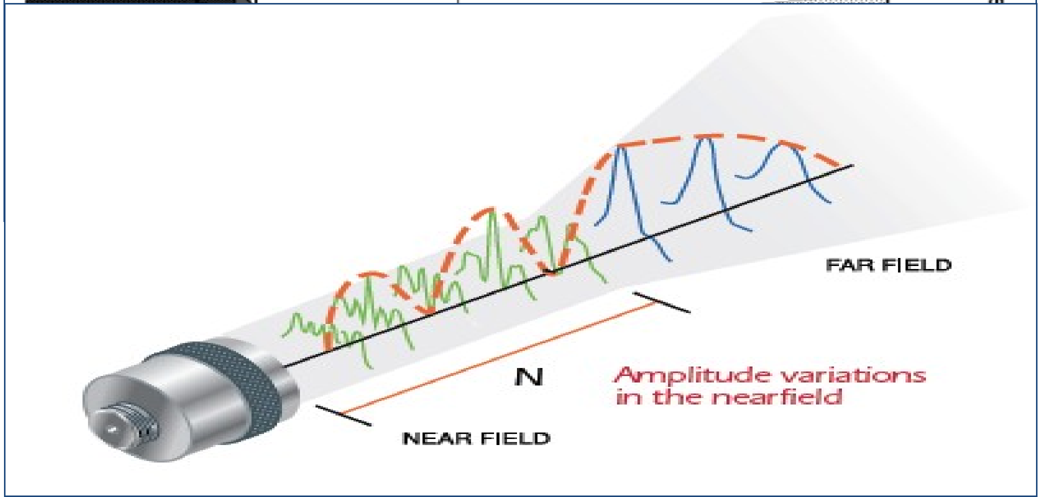


Figure 3.7.5a, Variation of Amplitude in Near- Field and Far- Field Region [28]

Near-Field: Since the ultrasound originates from a number of points along the transducer face, the ultrasound intensity along the beam is affected by constructive and destructive wave interference. These are sometimes also referred to as diffraction effects. This wave interference leads to extensive fluctuations in the sound intensity near the source and is known as the near field. Because of acoustic variations within a near field, defects of same size will give different echo amplitudes and the flaw evaluation in this field can lead to errors.

$$\text{Near field length} \quad N = \frac{D2}{4\lambda} = \frac{D2F}{4V}$$

Thus the near field length depends on the diameter of the probe (D), frequency (F) and the sound velocity (V) of the material to be tested.

Far Field: The pressure waves combine to form a relatively uniform wave front at the end of the near field. The area beyond the near field where the ultrasonic beam is more uniform is called the far field. In the far field, the beam spreads out in a pattern originating from the center of the transducer. The transition between the near field and the far field occurs at a distance, ***N***, and is sometimes referred to as the "natural focus" of a flat (or unfocused) transducer. The near/far field distance, ***N***, is significant because amplitude variations that characterize the near field change to smoothly declining amplitude at this point. The area just beyond the near field is where the sound wave is well behaved and at its maximum strength. Therefore, optimal detection results will be obtained when flaws occur in this area.

Beam Spread (or Beam Divergence): Beam spreading occurs in all ultrasonic beams. In near field, the beam is taken to roughly cylindrical and the same diameter as the transducer crystal. Beyond the near field (far field) the beam spreads out like a cone. This spreading reduces the intensity of the wave at each discrete point and, as a result, lowers the amount of energy that could be reflected at a defect. This phenomenon is combated through the use of Distance Amplitude Correction (DAC).

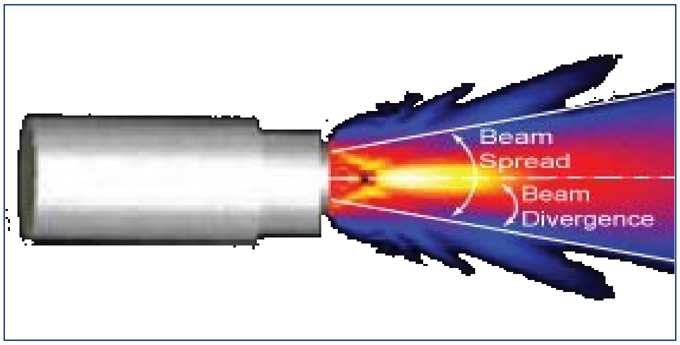


Figure 3.7.5b, Beam Spread

It should be noted that there is actually a difference between beam spread and beam divergence. Beam spread is a measure of the whole angle from side to side of the main lobe of the sound beam in the far field. Beam divergence is a measure of the angle from one side of the sound beam to the central axis of the beam in the far field. Therefore, beam spread is twice the beam divergence. The angle of beam spread "θ" can be calculated by the following formula.

$$\theta = \sin^{-1}\left(\frac{1.22\lambda}{D}\right)$$

Beam spread occurs because the vibrating particle of the material (through which the wave is traveling) does not always transfer all of their energy in the direction of wave propagation. Recall that waves propagate through the transfer of energy from one particle to another in the medium. If the particles are not directly aligned in the direction of wave propagation, some of the energy will get transferred off at an angle. In the near field, constructive and destructive wave interference fills the sound field with fluctuation. At the start of the far field, however, the beam strength is always greatest at the center of the beam and diminishes as it spreads outward. Beam spread is largely determined by the frequency and diameter of the transducer.

- Beam spread is greater when using a low frequency transducer than when using a high frequency transducer.
- As the diameter of the transducer increases, the beam spread will be reduced.

Although beam spread must be considered when performing an ultrasonic inspection, it is important to note that in the far field, the maximum sound pressure is always found along the acoustic axis (centerline) of the transducer. Therefore, the strongest reflections are likely to come from the area directly in front of the transducer.

3.7.6- The Speed of Sound in Solid Materials:

The speed of sound within a material is a function of the properties of the material and is independent of the amplitude of the sound wave. Because of difference in material properties, sound travel at different speeds in different materials. The general relationship between the speed of sound in a solid and its density and elastic constants is given by the following equation:

$$V = \sqrt{\frac{C}{\rho}}$$

Where **V** is the speed of sound, **C** is the elastic constant, and **ρ** is the material density. When calculating the velocity of a longitudinal wave, Young's Modulus and Poisson's Ratio are commonly used. When calculating the velocity of a shear wave, the shear modulus is used.

Chapter: 4

Pulse Echo Ultrasonic Testing Technique

4.1- Pulse Echo Testing Technique:

Pulse echo testing method most widely used in the ultrasonic testing of materials. This method utilizes the reflected part of the ultrasonic waves. In this method, the transmitter and receiver probes are on the same side of the specimen. The presence of a defect is indicated by the reception of an echo before that of the backwall echo.

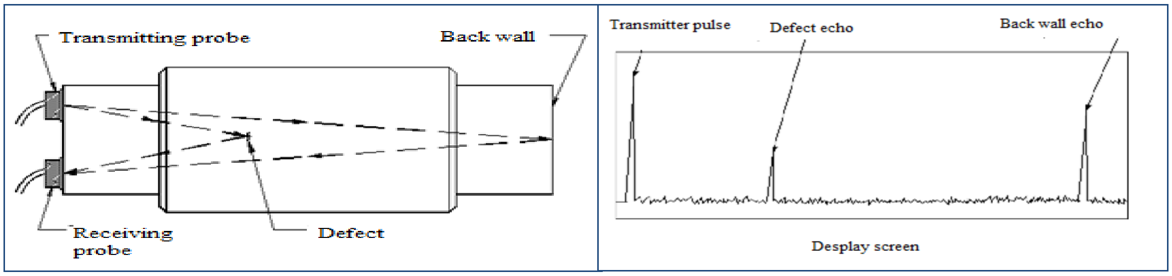


Figure 4.1a, Pulse Echo Testing Technique [26]

In this inspection method a pulsed ultrasonic beam is sent through the couplant into the test specimen. First the beam is reflected from the top of the test component. The ultrasonic wave travels through the material at a velocity dependent upon the material's properties. The ultrasonic wave travels through the material until a discontinuity (i.e., a defect) or the test specimen boundary reflects the signal. The reflected signal travels back through the material to a receiver. The receiver converts the mechanical energy back to electrical energy, which is then amplified. The amplified signal or echo is displayed on the instrument screen as an A-scan. The horizontal axis of the display is proportioned to the time elapse and the vertical axis corresponds to the amplitude of the echo. In pulse-echo testing, the presence, size, and location of a defect are related to the echo signal amplitude and the time at which the echo signal arrives at the receiver. The portion of energy that is reflected is highly dependent on the size of the reflecting surface with respect to the energy of incident ultrasonic beam. So, in the echo pattern a flaw can be recognized by the relative position and amplitude of its echo.

Variables which affect the amplitude of the received echo: The amplitude of the received echo in pulse-echo testing depends on several influencing factors:

- Transmitter power.
- Direction of transmission.
- Size of the reflector.
- Position and orientation of the reflector.
- Attenuation of sound wave due to absorption and scattering.
- Shadow effects.

Effect of distance on reflected ultrasonic signal: The signal amplitude from two equivalent defects is reduced for the defect at a greater distance.

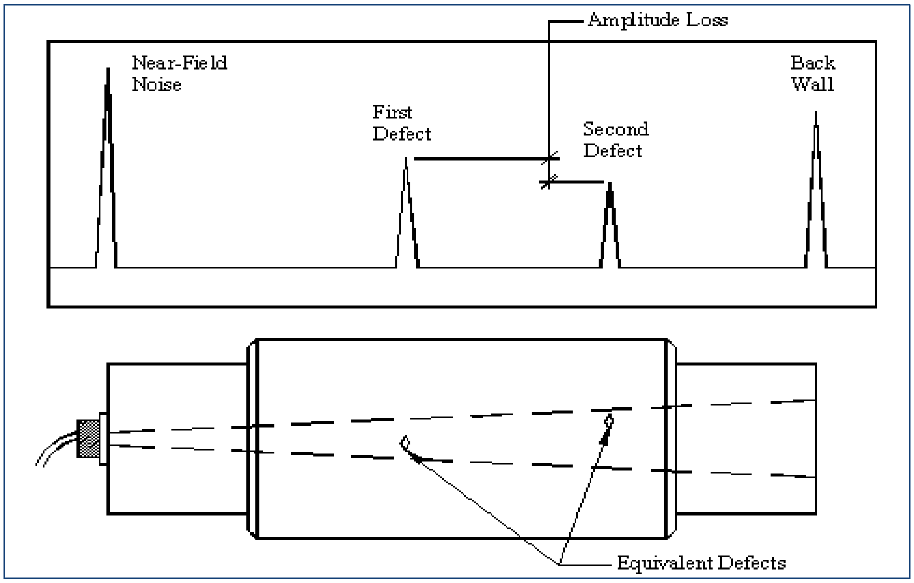


Figure 4.1b. Effect of Flaw Distance on Reflected Ultrasonic Signal [26]

Influence of sh ler defect is
masked by the l

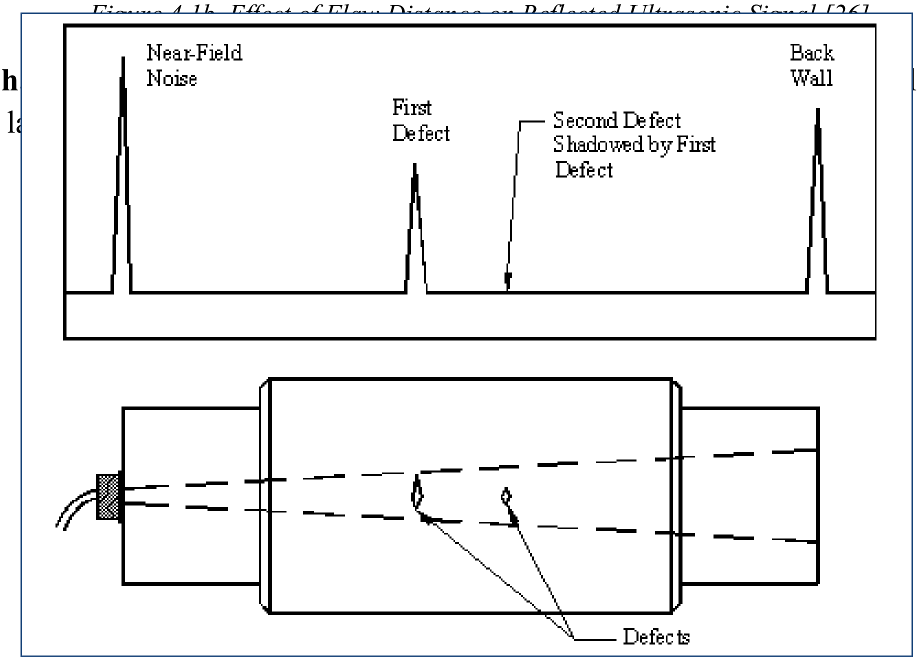


Figure 4.1c, Influence of Shadow Effects on Ultrasonic Signal [26]

Effect of defect orientation on ultrasonic signal: Figure illustrates the effect of defect orientation. Although this figure indicates that no signal would be detected, this really is not the case. Rather, a much reduced signal would actually be detected as a result of scattering of the beam at the defect.

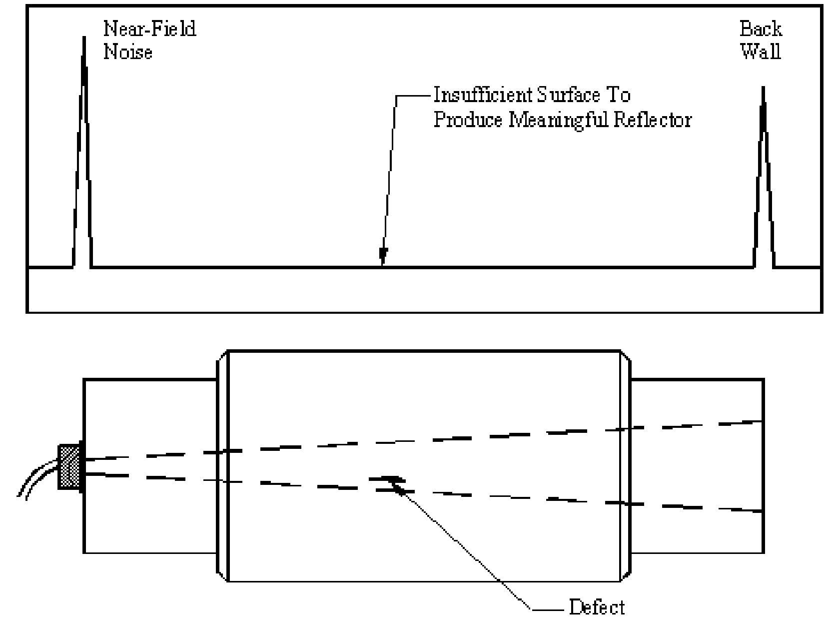


Figure 4.1d, Effect of Defect Orientation on Ultrasonic Signal [26]

Influence of def er defect will reflect more ultra

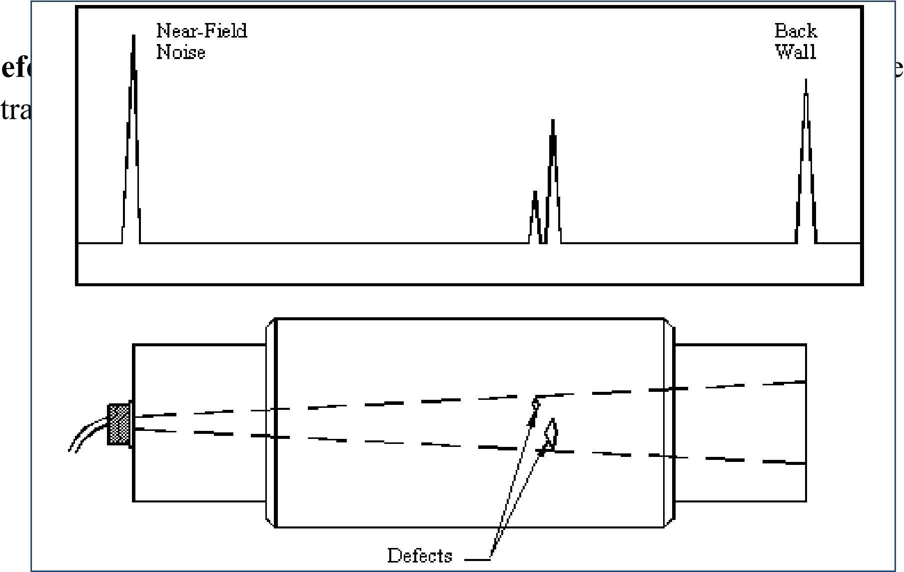


Figure 4.1e, Influence of Defect Size on Ultrasonic Signal [26]

4.2- Pulse Echo Testing Methods:

In order to decide whether a particular flaw is acceptable or not, it is essential to know its nature (crack, inclusion, porosity etc), size and, location. The various type testing methods which are used for flaw detection are-

1- Contact Testing
    - Normal Beam Testing (or Straight Beam Testing)
    - Angle Beam Testing

2- Immersion Testing

4.2.1- Contact Testing:

In contact testing, the probe is brought in contact with the test specimen through a thin layer of couplant and the energy reflected from a flaw is picked up by the probe and is presented on the CRT screen.

Normal Beam Testing: In normal beam testing, the ultrasonic beam is projected perpendicularly in to the test specimen. Usually, longitudinal waves are used in normal beam technique. The nature of the flaw may be judged from the shape of the echo obtained from the flaw. Echo from planner defects like crack and lack of fusion are sharp with high amplitude. Slag inclusion produces a pine tree like echo of high amplitudes. A pore being poor reflector produces tiny echoes.

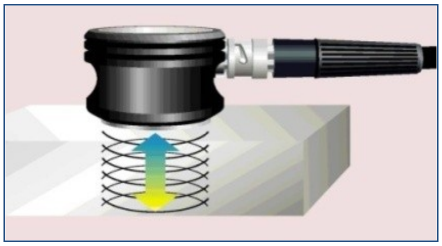


Figure 4.2a, Normal Beam Testing

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 2 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

$$\mathbf{d = v\times t/2 \quad or \quad v = 2d/t}$$

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.

Angle Beam Testing: The angle beam testing is used to transmit ultrasonic waves into a test specimen at a predetermined angle to the test surface. Usually, transverse waves or shear waves are used in angle beam technique. Due to the fact that steel is tested in most applications, the angle-beam probes are designed so that suitable angles of incidence are produced in steel. To achieve clear evaluation there are angle-beam probes with angles of 35°, 45°, 60°, 70°. For inspection of steel, probe angles 45°, 60° and 70° most commonly used.

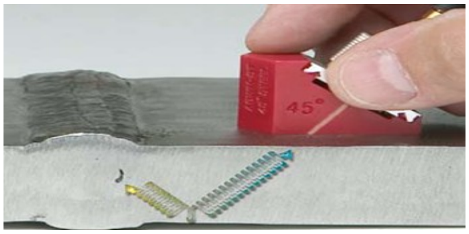


Figure 4.2b, Angle Beam Testing

4.2.2- Immersion Testing:

In the immersion technique both the probe and the test specimen are immersed in water. The ultrasonic beam is directed through the water in to the test specimen, using either a normal beam technique for generating longitudinal waves or an angle beam technique for generating transverse waves. This technique mainly used for testing the specimen which having irregular surface conditions.

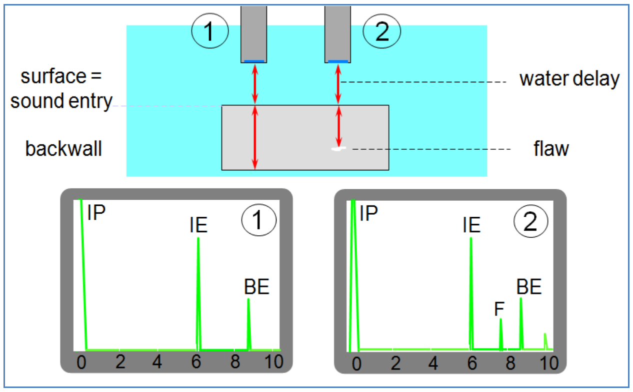


Figure 4.2c, Immersion Testing [26]

Advantages:

- This technique permits inspection of rough and irregular surfaces.
- Uniform couplant conditions can be achieved.
- Longitudinal and transverse waves can be generated with the same probe simply by changing the incident beam angle.
- Higher frequency may be used so that smaller defects closer to the surface can be detected.

4.3- Other Ultrasonic Testing Technique:

4.3.1- Through Transmission Testing:

Ultrasonic waves arriving at an interface between two media are partially reflected into the medium from which they are incident and partially transmitted into the other medium. The method of ultrasonic testing which utilizes the transmitted parts of the ultrasonic waves is called through transmission method.

In this method, two ultrasonic probes are used. One is the transmitter probe and the other is the receiver probe. These probes are situated on opposite side of the specimen to be tested as shown in fig.

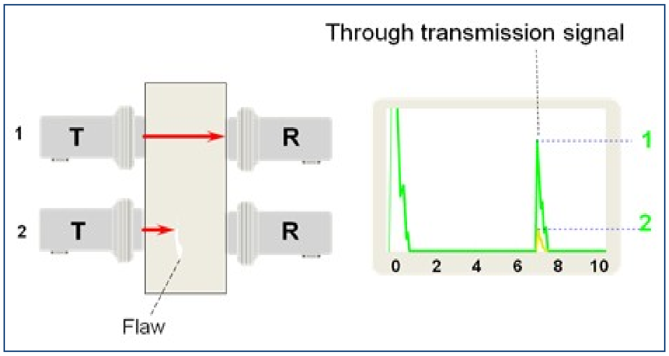


Figure 4.3a, Through Transmission Testing [26]

In this method, the presence of an internal defect is indicated by the reduction in signal amplitude, or in case of gross defects, complete loss of the transmitted signal. Since defect in the specimen decreases the amplitude of the transmitted beam because of the reflection and scattering that take place. This method is used when attenuation is high and gross defects are present.

This method suffer from the following major disadvantages-

- The method does not give the size and location of the defect.

- Accurate positioning of the two search units with respect to each other is essential.
- Good coupling between the search units and test material is essential.

4.3.2- Resonance Testing:

The resonance system makes use of resonance phenomenon to measure thickness of material and also to detect gross defects. A condition of resonance exists whenever the thickness of a material equals half the wavelength of sound in that material. Control of wavelength in ultrasonic's is achieved by control of frequency. If we have a transmitter with variable frequency control, it can be tuned to create a condition of resonance for the thickness of plate under test. This condition of resonance is easily recognized by the increase of received pulsed amplitude.

In this system ultrasonic waves from the transducer are transmitted into the test piece under inspection and the reflected beam is received by the same transducer as in pulse echo system, but the ultrasonic waves are always continuous longitudinal waves. Wave frequency is varied until standing waves are set up in the system, causing the item to vibrate at greater amplitude. When resonance occurs, there is increase in the energy drawn by the transducer and that can be indicated by a display on CRT screen.

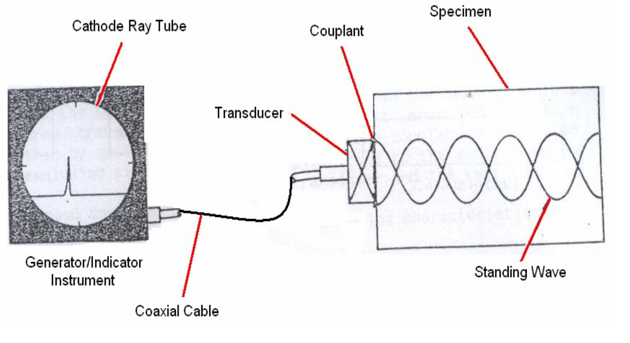


Figure 4.3b, Resonance Testing [26]

In a standing wave, the points of maximum displacement are known as antinodes and the point of minimum displacement as nodes. The distance between adjacent nodes or antinodes is a half wavelength. In resonance testing there is always an antinode at the transducer and an antinode at the opposite side of the test piece. At the fundamental resonant frequency and its harmonics, amplitude peaks are observed on the CRT screen. This technique for flaw detection consists of moving the transducer over the specimen and watching for significant changes in the resonance peaks.

Chapter: 5

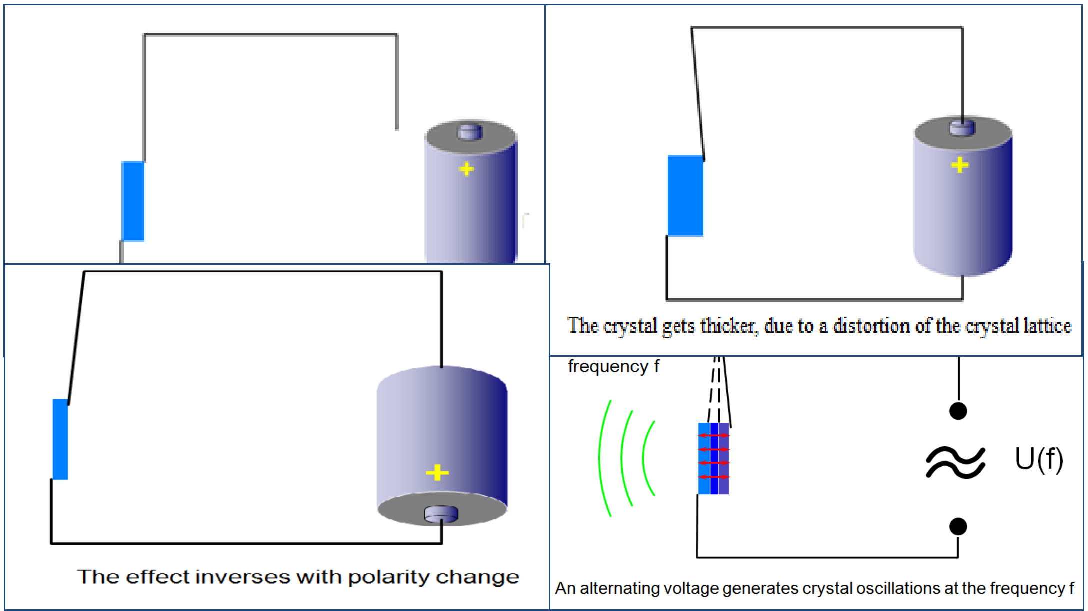
Equipments for Ultrasonic Testing

5.1- Ultrasonic Probe:

The ultrasonic waves are generated by a device called probe. The ultrasonic waves are usually produced by "Piezoelectric effect". A probe contains a crystal of piezoelectric materials that vibrates at a natural frequency in the required range and produces the ultrasonic sound.

5.1.1- Piezoelectric Effect:

Crystals of piezoelectric material, when subjected to an alternating electric charge expand and contract (vibrate) under the influence of these charges. Conversely, if these materials are subjected to alternate tension and compression forces they will develop alternating electric charges on their faces. This is known as piezoelectric effect. Thus a piezoelectric material converts electrical signals into mechanical vibrations and mechanical vibrations into electrical signals. The most common types of piezoelectric materials used for ultrasonic inspection are Quartz, Lithium Sulphate, Barium titanate etc.



The crystal gets thicker, due to a distortion of the crystal lattice

The effect inverses with polarity change

An alternating voltage generates crystal oscillations at the frequency f

Figure 5.1a Piezoelectric Effect

Direct Piezoelectric Effect: When mechanical vibration or pressure is applied on a crystal of piezoelectric material, these vibrations converted into electrical energy. This effect is known as direct piezoelectric effect. The magnitude of electrical energy produced directly proportional to the magnitude of mechanical vibration applied. The sign of electrical charge depends on the nature of mechanical vibration (tension or compression).

Inverse Piezoelectric Effect: When electrical field is applied on a crystal of piezoelectric material, electrical energy is converted into the mechanical vibrations. This effect is known as inverse piezoelectric effect. Thus a transmitter probe works on the inverse piezoelectric effect and receiving probe works on the direct piezoelectric effect.

5.1.2- Types of Ultrasonic Probe:

Ultrasonic probes are manufactured for a variety of applications and can be custom fabricated when necessary. Careful attention must be paid to selecting the proper probe for the application. We know that it is important to choose probe that have the desired frequency, bandwidth, and focusing to optimize inspection capability. Probes are classified into groups according to the application.

- Normal beam probe
- Angle beam probe
- TR probe or dual element probe

Normal Beam Probe: Probes whose sound beams are normal to the surface of the specimen are called normal beam probes. Most standard straight-beam probes transmit and receive longitudinal waves for inspection. The normal beam probes, as shown in figure 4.2a, used for the inspection of plate, billets, bar, forging casting etc. The main disadvantage of using normal beam probe is poor recognition of near-to-surface discontinuities due to the width of the initial pulse.

Angle Beam Probes: Probes whose sound beams enter at an angle are called angle-beam probes because they transmit and receive the sound waves at an angle to the surface of the test object figure 4.2b. Most standard angle-beam probes transmit and receive, transverse waves or shear waves for inspection. The angle of the beam is determined by the wedge angle. Angle beam transducers allow inspections in areas of a part that cannot be accessed by the normal probe. A common use for angle beam transducers is in weld inspection; where a weld bead cannot inspect by the normal probe and where typical flaw alignment produces stronger reflections from an angled beam.

Transmitter and Receiver Probes (TR Probes): A TR probe consists of two piezoelectric crystal elements (one transmitter and one receiver) housed in the same case and isolated from one another by an acoustic barrier. One element transmits longitudinal waves, and the other element acts as a receiver. The elements are angled slightly towards each other to bounce a signal off the backwall of a part in a V-shaped pattern.

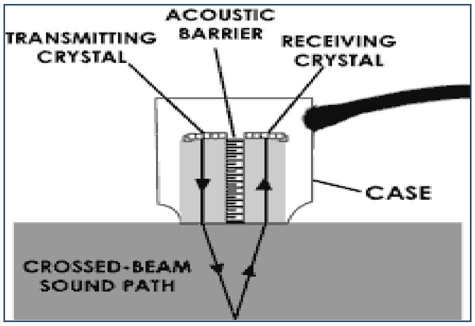


Figure 5.1b, TR Probe [28]

Advantages

- Improves near surface resolution.
- Can be used in high temperature applications.
- Couples well on rough or curved surfaces.
- Reduces direct back-scattering noise in coarse grained or scattering materials.

5.1.3- Characteristics of Ultrasonic Probes:

A probe is a very important part of the ultrasonic inspection system. Many factors, including material, mechanical and electrical construction, and the external mechanical and electrical load conditions, influence the behavior of a probe. The various characteristics of a probe are-

- Sensitivity
- Resolution
- Dead zone

- Probe delay

Sensitivity: Sensitivity is the ability of an ultrasonic system to detect the smallest discontinuity at a given depth in a test material. The greater the signal that is received from a given defect, the more sensitive the transducer system.

Resolution: Resolution is the ability of an ultrasonic system to produce simultaneous and distinct echoes from two or more defects located close together in depth. A long pulse has poor resolving power. Very short pulses are desirable for high resolution.

Dead Zone: When a small flaw present just below the surface of the test object and in front of the probe, cannot be inspected. This non-testable area is called dead zone. This phenomenon occurs because when flaw present just below the surface, the flaw echo is lies within the initial pulse, it is therefore covered by it.

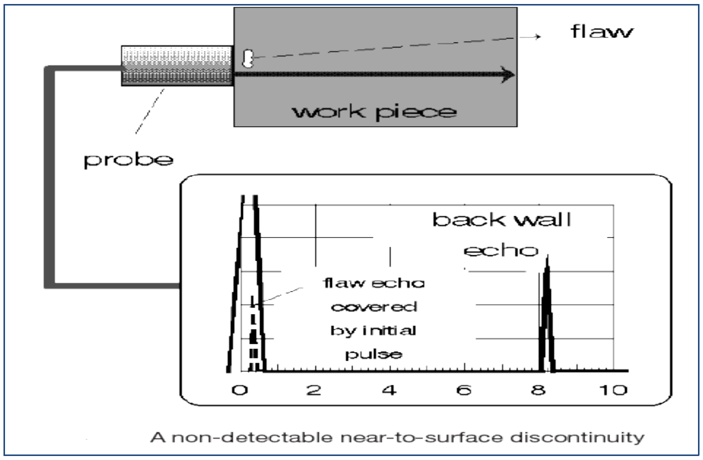


Figure 5.1c, Flaw Echo Covered by Initial Pulse [28]

To minimize dead zone, short pulses can be used. Dead zone is minimum when immersion or delay line probe are used for testing purpose.

Probe Delay: When a piezoelectric crystal start producing sound pulses, sound energy is not fed directly to the surface of the test object. Before sound fed to the surface it travels through the

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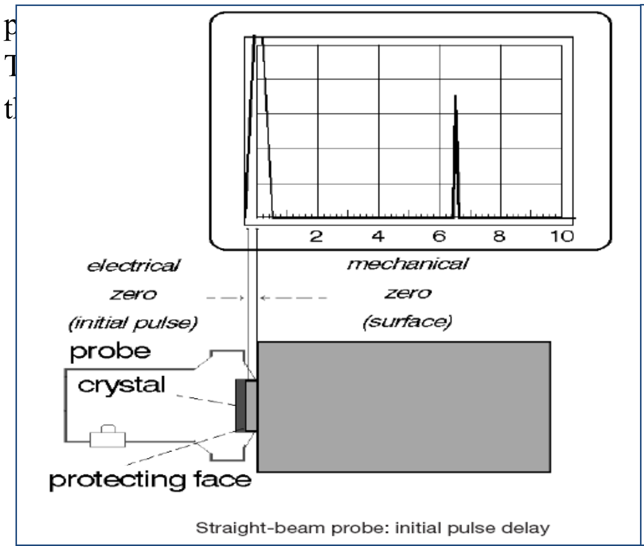


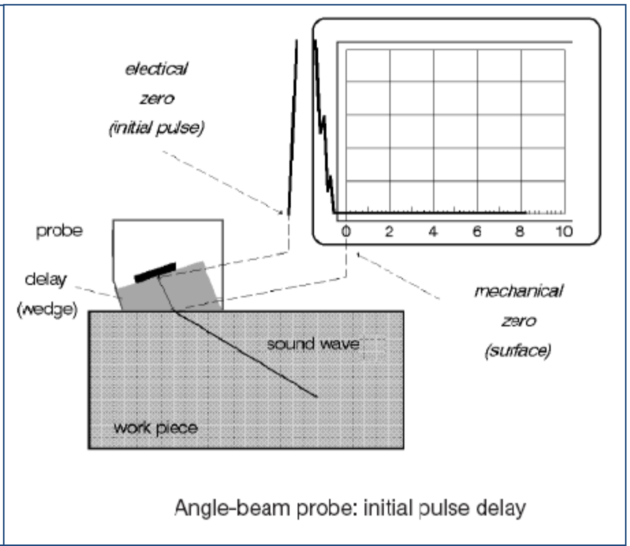


Figure 5.1d, Probe Delay in Normal and Angle Beam Testing [28]

5.2- Acoustic Couplant:

Air is a poor transmitter of sound waves at megahertz frequencies. Also the impedance between air and most solids is great enough that even a very thin layer of air will severely retard the transmission of sound waves from the transducer to the test piece. To perform satisfactory contact inspection it is necessary to eliminate air between the transducer and the test piece by a coupling method. In this method, couplant is used. The couplant, as the name implies, couples the transducer to the test specimen. A couplant is used between the transducer face and the test surface to ensure sufficient sound transmission from transducer to test surface. The couplant accomplishes this by smoothing out the irregularities to the surface and by excluding all air between the transducer and the test surface.

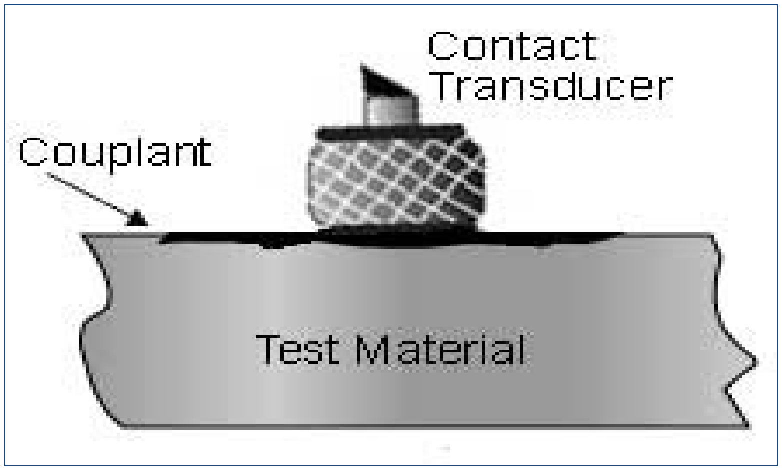


Figure 5.2, Acoustic Couplant Between Probe and Test Material

A good couplant should have the following characteristics:-

- Easy to apply.
- Homogeneous and free of air bubbles, or solid particles in the case of a non-solid.
- Harmless to the test specimen and transducer.
- Able to wet both the surface of the test specimen and the face of the transducer.
- Has a tendency to stay on the test surface, but it is easy to remove, and
- Has acoustic impedance between that of the transducer face and the test specimen.

Couplants normally used for contact inspection include water, oils, glycerin, petroleum greases, silicone grease, wall paper paste and various commercial pastes like substance. The choice of couplant depends primarily on the condition of the surface contacted by the transducer. In immersion testing, clean deaerated water, with an added wetting agent is used for a couplant.

5.3-Calibration and Reference Blocks:

5.3.1- Calibration Block:

In ultrasonic testing a calibration blocks is used to calibrate the equipment. Calibrating means optimal adjustment of equipment parameters so that the indications, got by the ultrasound beam, to be correctly located. In pulse echo testing method, calibration block mainly used to-

- Determine the operating characteristics of the flaw detector and probe
- Establish reproducible test conditions.

IIW (V1) Calibration Block: This block is most widely used and has been described by the International Institute of welding and proposed by the International Standard Organization (ISO). This block used for the calibration of normal and angle beam probe. The rectangular section of this block is used for calibration with normal probe in thickness measurement. The curved section is used with calibration of angular probe.

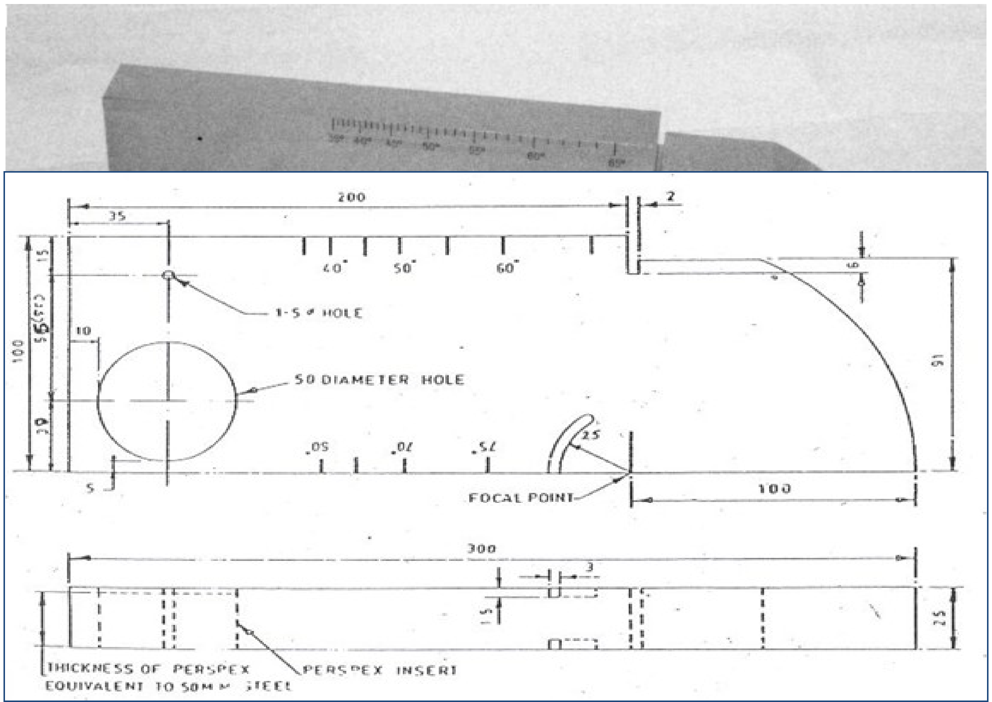


Figure 5.3a, IIW (V1) Calibration Block

This block is generally used

- To perform time - base calibration for normal and angle beam probes
- To determine probe index
- To determine the probe angle
- For checking the performance characteristics (time base linearity, resolution, dead zone etc) of the ultrasonic flaw detector.

IIW (V2) Calibration Block: The IIW (V2) block has two curved faces of radius 25mm and 50mm. The V2 block generally used for setting the range of smaller thickness workpiece. This block is particularly suitable for the time base calibration of small diameter normal and angle probes. It is used for calibration of time base, partial range calibration, determination of probe index and probe angle.

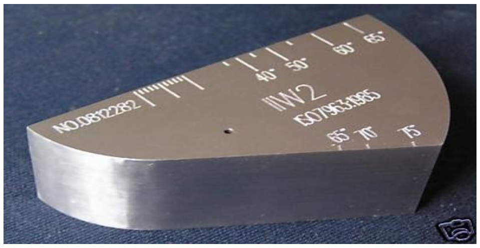


Figure5.3b, IIW (V2) Calibration Block

5.3.2- Reference Block:

A test block used to compare the height or location of the echo from a flaw in the test specimen to that from an artificial flaw in the test is called a reference block. In a pulse-echo type setup, signal strength depends on both the size of the flaw and the distance between the flaw and the transducer. The inspector can use a reference block with an artificially induced flaw of known size and at approximately the same distance away for the transducer to produce a signal. By comparing the signal from the reference block to that received from the actual flaw, the inspector can estimate the flaw size.

Area-Amplitude Blocks: An Area-amplitude block provides artificial flaws of different sizes at the same depth. Eight blocks made from the same 2” diameter round stock. Each block has a ¾” deep flat bottom hole drilled in the centre of the bottom surface. Area-amplitude blocks have a constant 3-inch metal path distance and the hole sizes are varied from 1/64" to 8/64" in 1/64" steps.

Figure5.3c, Area Amplitude Block

The area- amplitude blocks are used to determine the relationship between flaw sizes and signal amplitude by comparing signal responses for the different sized holes. The amplitude of the echo from a flat bottom hole in the far field of a normal beam probe is proportional to the area of the bottom of the hole. Therefore these blocks can be used to check linearity of a pulse echo inspection system and to relate echo amplitude to the area.

Distance-Amplitude Blocks: A distance- amplitude block provides artificial flaws of a given size at various depths. Distance- amplitude blocks can be used to check actual variation of amplitude with distance for normal beam inspection in a given material.

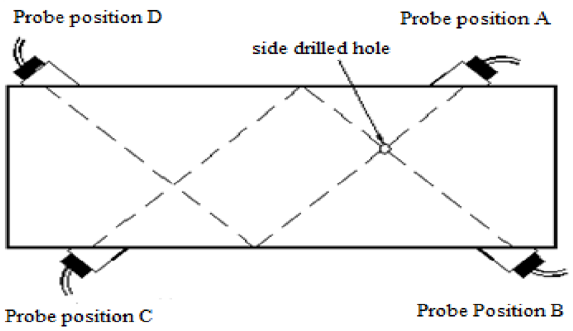
Figure5.3d, Distance Amplitude Block

ASME Reference Block: This block is made from the same material and same thickness as that of the specimen to be tested and contains a side drilled hole whose diameter depends on the thickness of the specimen. Generally three holes drilled at T/4, T/2 and 3T/4 positions (T-thickness) at three different locations. This block is used to construct a DAC curve on the CRT screen by noting the changes in echo amplitudes from the hole with change in scanning distance.

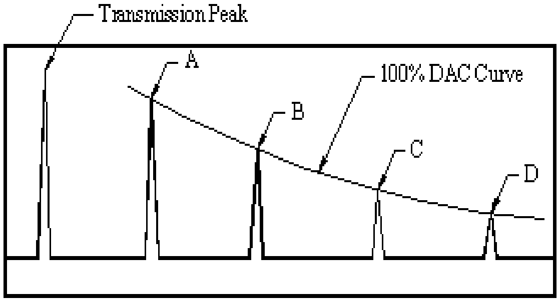
5.4- Distance Amplitude Correction (DAC):

Because of beam spread and attenuation, echo heights observed from equivalent defects decrease with increased distance. Consequently, a technique known as distance amplitude correction (DAC) is commonly employed to adjust signals generated at different distances for comparison purposes. This technique consists of generating a DAC curve that essentially indicates that a smaller echo at a greater distance may have similar properties to a larger echo at a lesser distance.

Construction of a DAC involves the use of reference standards which incorporate side drilled holes, flat bottom holes, or notches whereby the reflectors are located at varying depths. It is important to recognize regardless of the type of reflector that is used in constructing the DAC, the size and shape of the reflector must be constant over the sound path distance. Commercially available reference standards for constructing DAC include ASTM Distance/Area Amplitude and ASTM E1158 Distance Amplitude blocks, and ASME Basic Calibration Blocks. However, generating the same curve with an angle transducer is typically completed using a specimen with side-drilled holes. Regardless of the technique used to generate a DAC curve, the material used in the calibration block should be the same as the material in the test specimen due to potential differences in attenuation characteristics.



Transducer and hole location for generating DAC curve.



Resulting DAC curve.

Figure 5.4, Distance Amplitude Correction Curve [26]

5.5- Ultrasonic 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.

A-Scan Presentation: 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 is displayed along the horizontal axis. The heights of vertical deflections represent amplitudes of echoes.

- 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 axis.

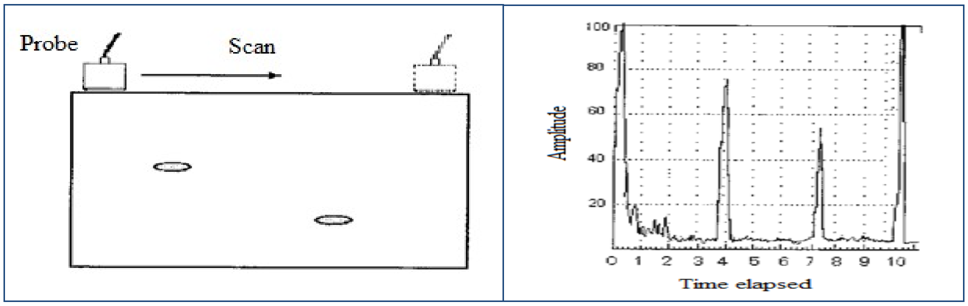


Figure5.5a, A-scan Data Presentation

B-Scan Presentation: The B-scan presentation is shows a 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.

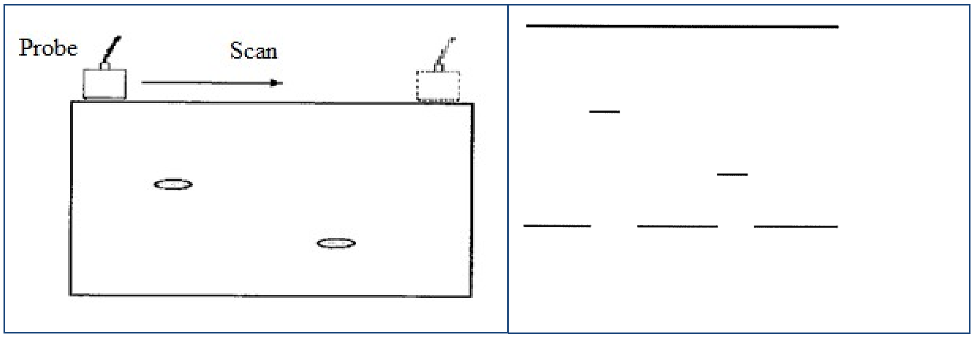


Figure 5.5b, B-scan Data Presentation

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.

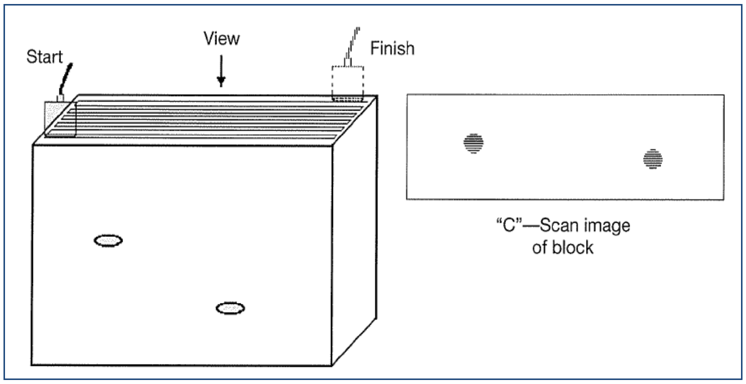


Figure 5.5c, C-scan Data Presentation

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.

Chapter: 6

Welding Defects

6.1 Welding Defect:

The performance of welded structure or component in service depends upon the quality of welding which in turn is based on the presence or absence of defect s in weld joint. It has been suggested by various authorities that the term defect should be reserved for fault which are likely to be or detrimental to the service life, especially if they are situated in highly stressed region. On the other hand, the same faults could be termed as imperfection, or flaw or discontinuities if they are situated in region of low stress. Defect impairs the strength of weld joint and may result in failure of a whole structure in service.

6.2 General Source of Weld Defects:

The following are the general sources of defects for most of the conventional welding processes [29].

- Too long arc length
- Incorrect welding speed
- High alloy composition
- Rapid cooling
- Insufficient heat input rate

- Poor joint preparation
- Incorrect electrode size
- Incorrect welding technique
- Improper selection of welding process
- Gases entrapped during solidification
- Inadequate gas shielding of the arc

6.3 Types of Welding Defect:

There are various kinds of welding defects which generally occurs in weld bead. The defect may be present at the surface or inside the weld bead. The major types of weld defects are-

- Cracks
- Undercut
- Lack of fusion or incomplete fusion
- Solid inclusion (slag inclusion and metallic inclusion)
- Incomplete penetrations
- Porosity

Crack: The fractures in the weld itself or in the metal adjacent to it termed as crack. Crack occurs because of the stress at that point in the weldments exceeds the ultimate tensile strength or ultimate shear strength of the base metal or weld metal. The main cause of weld cracking is the temperature gradients and embrittlement of grain boundaries due to alloying element. The various forms of welding cracks are shown in figure.

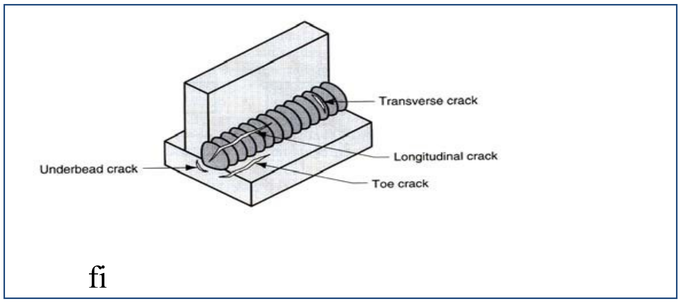


Figure 6.3a, Different Types of Cracks in Weld

Undercut: Undercuts are groove or notch formed at the parent metal or on weld bead face and left unfilled by the weld metal.

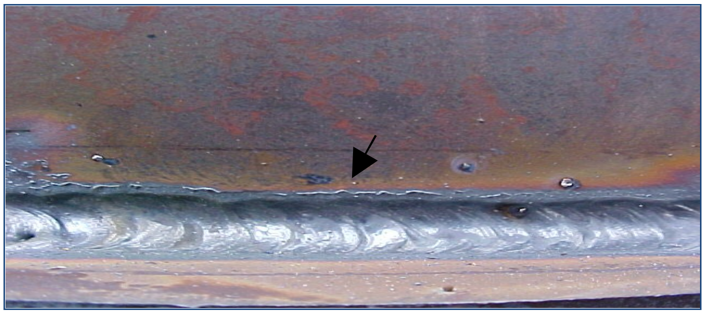


Figure 6.3b, Undercut in Weld

Lack of Fusion: A weld bead that does not fill the entire joint cross-section area by the molten metal is termed as lack of fusion.

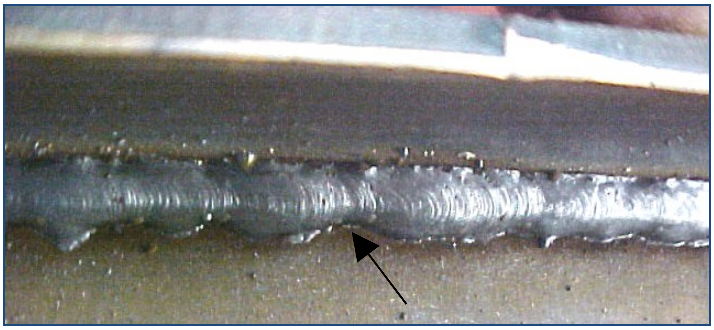


Figure 6.3c, Lack of Fusion in Weld

Incomplete Penetrations: Penetration can be defined as the perpendicular distance from the base plate top surface to the maximum extent of the weld nugget. If the molten metal fails to penetrate the base metal up to a specified depth, than it is known as incomplete penetration.

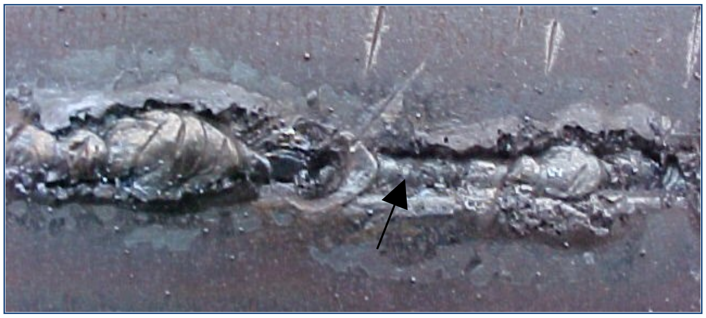
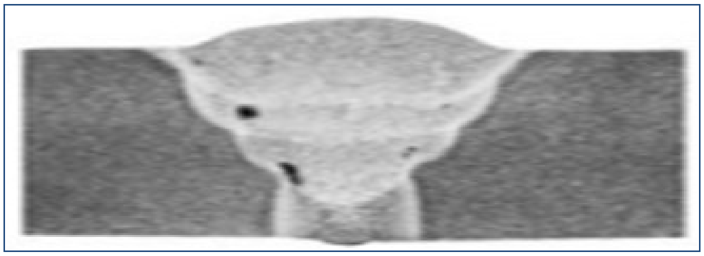


Figure 6.3d, Incomplete Penetration in Weld

Solid Inclusions: Slag inclusion refers to solidified molten flux like oxides, sulphides, phosphorus compounds, and nitrides entrapped in the weld metal and parent metal which fails to float out to the surface.



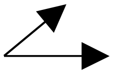


Figure6.3e, Solid Inclusions in Weld

Metallic inclusions are mostly tungsten and copper inclusion. Tungsten inclusion occurs from the tungsten electrode in TIG welding and copper inclusion occurs from the contact tip in MIG welding.

Porosity: It can be define as a hole or cavity found internally or externally in the weld bead. Porosity in welding is caused by the presence of gases which get entrapped during the solidification of weld. Porosity can originate from wet electrodes, electrodes flux breaking down or from impurities on the surface of the parent metal.

Figure 6.3f, Porosity in Weld

Chapter: 7

Ultrasonic Inspection of Weld Joint

7.1-Inspection of Welds:

The weld inspection involves using an angle beam transducer to inspect the actual weld area. Angle beam transducers use the principles of refraction and mode conversion to produce refracted shear in the test material. This inspection may include the root, sidewall, crown, and heat-affected zones of a weld. The process involves scanning the surface of the material around the weldment with the ultrasonic probe. This refracted sound wave will bounce off a reflector (discontinuity) in the path of the sound beam. With proper angle beam techniques, echoes returned from the weld zone may allow the operator to determine the location and type of discontinuity. There are two advantages of angle beam testing of weld joints:

- Energy transfer is more efficient at the incident angles that generate shear waves in steel and similar materials.

- Minimum flaw size resolution is improved through the use of shear waves. Since at a given frequency, the wavelength of a shear wave is approximately 60% the wavelength of a comparable longitudinal wave.

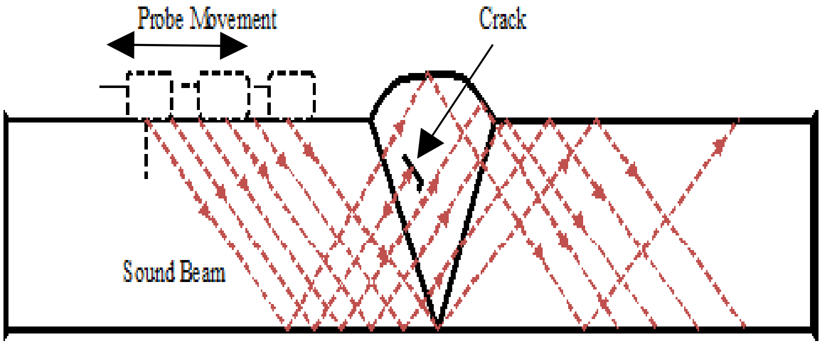


Figure7.1, Inspection of Weld with Angle Beam Probe

To determine the proper scanning area for the weld, the inspector must first calculate the location of the sound beam in the test material. Using the refracted angle, beam index point and material thickness, the V-path and skip distance of the sound beam is found. Once they have been calculated, the inspector can identify the transducer locations on the surface of the material corresponding to the crown, sidewall, and root of the weld [30].

7.2- Beam Path and Skip Distance of the Weld:

To determine the proper scanning area for the weld, the inspector must first calculate the location of the sound beam in the test material. Using the refracted angle, beam index point and material thickness, the beam-path and skip distance of the sound beam is found. Once they have been calculated, the inspector can identify the transducer locations on the surface of the material corresponding to the crown, sidewall, and root of the weld.

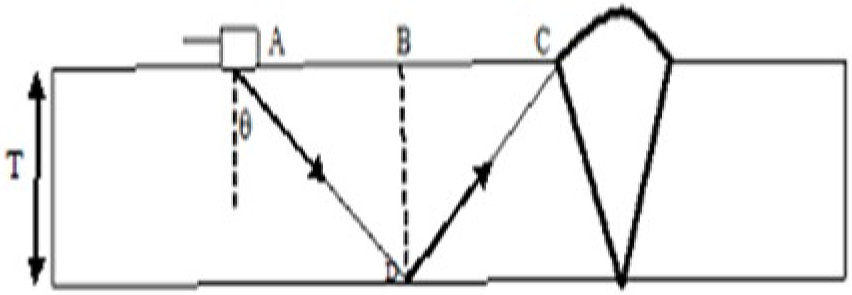


Figure 7.2, Metal Beam Path and Skip Distance

Distance AB = Half – Skip- Distance = $T \tan\theta$
Distance AC = Full – Skip- Distance = $2T \tan\theta$
Distance AD = Half Metal Beam Path = $T \sec\theta$
Distance AD + DC = Full Metal Beam Path = $2T \sec\theta$
Where θ = Probe angle

The selection of probe angle depends on the thickness of the workpiece and the bevel angle of the weld geometry which can be calculated as:

Required probe angle $\theta = 90 - T$
or $= 90 - \beta$

Where T is the thickness of the specimen to be tested and β is the half bevel angle of the weld [30-31].

7.3- Calibration of the Instrument:

Calibration process generally used:

- To determine probe index
- To determine the probe angle
- To range calibration

7.3.1- Measuring Probe Index:

Probe index is the exit point of sound beam from the probe. Due to scanning of the test specimen, the inner surface of the probe is worn out, resulting change in the probe index. So it is necessary to check the index point before starting inspection. The procedure for measuring the probe index is as follow [30-31]:

- Place the angle probe on the IIW block as shown in figure in such a way that the beam is directed towards the curvature forming the 100mm radius.
- Move the probe to & fro and find out the position giving the maximum echo amplitude.
- Extend the vertical mark at the centre of 100mm radius to the probe and this mark on the probe is the probe index.

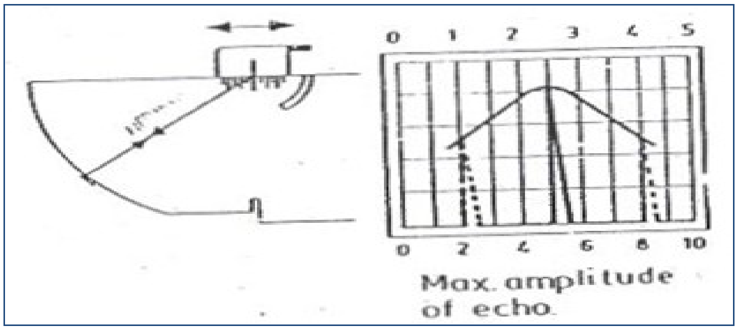


Figure 7.3a, Measurement of Probe Index

7.3.2- Measuring Probe Angle:

The angle of the probe can be found with the help of probe index and IIW (V1) block.

- Place the probe on the angles sides as marked on the calibration block. The sound beam will be reflected back either from the 50mm diameter perspex inserted or the 1/16" diameter hole, depending upon the angle of the probe.
- The probe is moved to & fro on either side of the angles as marked on the block, till maximum echo amplitude is obtained as shown in figure.
- As soon as we got an echo of maximum amplitude, stop the probe movement and compare the angle marked on the calibration block with the probe index point (already marked on the probe).
- The angle marked on the V1 block, corresponding to the probe index point, is the angle of sound beam.

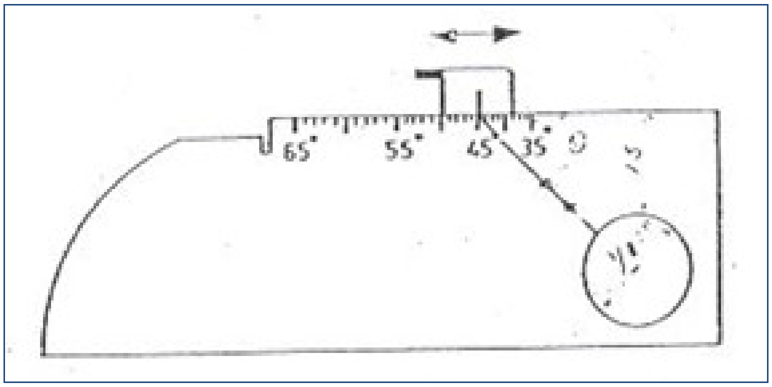


Figure 7.3b, Measurement of Probe Angle

7.3.3- Range Calibration:

The most important point which always applies for range calibration of all types of probes, is that minimum two reference point (echo indications) are necessary. This is because the error due to delay (the sound beam also has to traverse either the crystal facing material or the Perspex wedge before entering the test specimen). These points can be multiple backwalls or indications from known thickness blocks of similar material [30-31].

- The first reference point should always be controlled with the help of “Delay Control Knob”.
- The second reference point (second echo indication after the first) should always be controlled with the help of the “Range Control Knob”.
- Always the second reference point is first taken to set at the required scale division after that first reference point is shifted the required scale division. While doing so, the second reference point may change its position and hence the process is again repeated till both the reference echoes are placed at their respective scale divisions.

Range calibration with IIW (V1) block: The V1 block generally used for setting the range of higher thickness workpiece and calibration of range is carried out as follow:

- Place the probe on the IIW (V1) block (with vertical grooves starting at centre of 100mm radius) to obtain a maximum echo amplitude from the curved surface.
- Bring this echo indication to zero position of the horizontal scale using the delay control knob to position the second echo at 10th position of the horizontal scale.
- Bring back the 1st echo to zero position using delay control knob because in the previous adjustment this echo would have shifted its position.
- Repeat the procedure to position the 1st echo to 10th position on the horizontal scale as shown in figure.
- Now the distance between 0 – 10 on horizontal scale on CRT screen corresponds to 0 – 100 mm of the workpiece. Each subdivision reads 2mm.

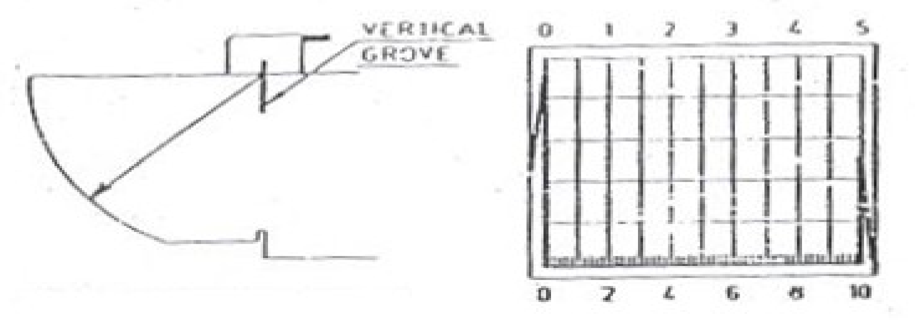


Figure 7.3c, Range Calibration with IIW (V1) Calibration Block having 100R Face only

In some IIW (V1) blocks two grooves having a radius of 25mm and 100mm is provided (in India this block is standardized). On such a block range calibration is carried out as follows:

- First the probe is positioned to direct the beam towards 25mm radius. Echo of maximum amplitude is obtained and positioned to read 2.5 on horizontal scale.
- Now the probe is turned in opposite direction (towards 100R face) and a maximum amplitude echo is obtained from 100mm radius face.
- Now use delay control and range control knob to adjust these two echo indications at position 2.5 and 10 on horizontal scale.

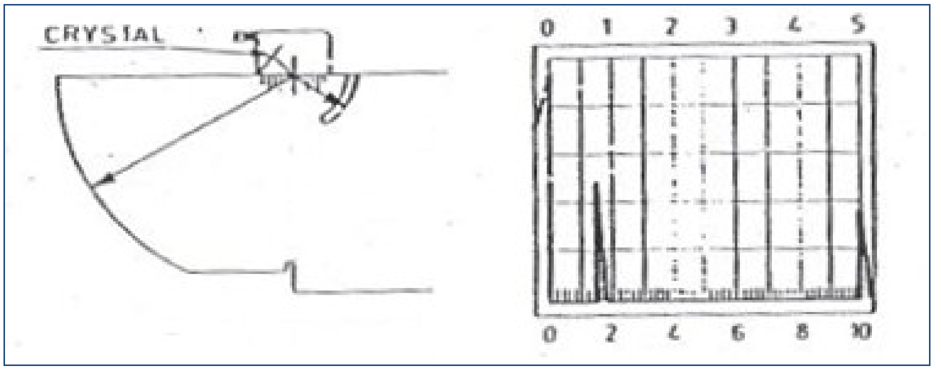


Figure 7.3d, Range Calibration with IIW (V1) Calibration Block having 25R and 100R Faces

Range calibration with IIW (V2) block: The IIW (V2) block has two curved faces of radius 25mm and 50mm. During calibration of range, the echo position depends on the face towards probe is placed. The required echo sequence is produced here by the alternating reflection of the sound wave [30-31].

Case: 1- Facing 25R face.

- 1st echo distance = 25mm (R)
- 2nd echo distance = 100mm (R)
- 3rd echo distance = 175mm (R)
- 4th echo distance = 250mm (R) and so on.

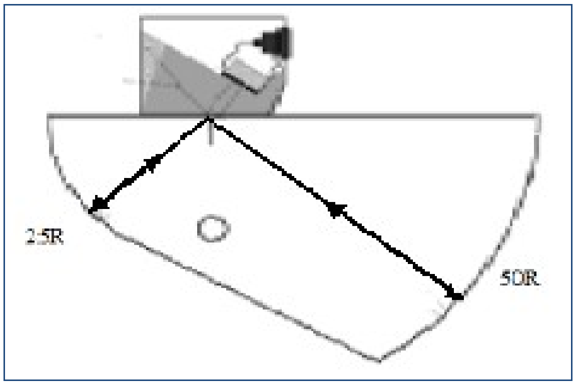


Figure 7.3e, Range Calibration by Facing 25R Face

Case: 2 - Facing 50R face.

- 1st echo distance = 50mm (R)
- 2nd echo distance = 125mm (R)
- 3rd echo distance = 200mm (R)
- 4th echo distance = 275mm (R) and so on.

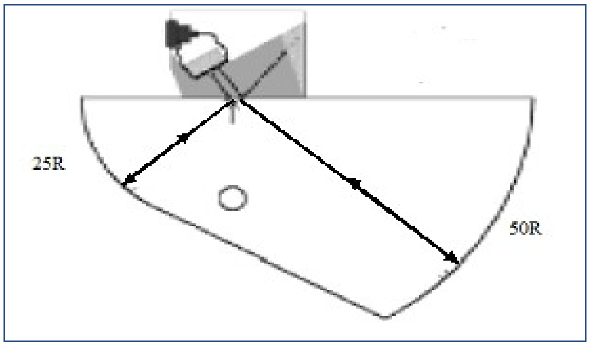


Figure 7.3f, Range Calibration by Facing 50R Face

Example 1: Calibrate the range 0 – 150 mm by facing the 25R face of V2 block.

$$\text{Big division} = \frac{\text{range}}{\text{number of division on CRT screen}}$$

$$\text{Small division} = \frac{\text{big division}}{\text{number of divisions within a big division}}$$

Generally CRT screen has 10 big divisions and one big division is divided into 5 small divisions as shown in figure.

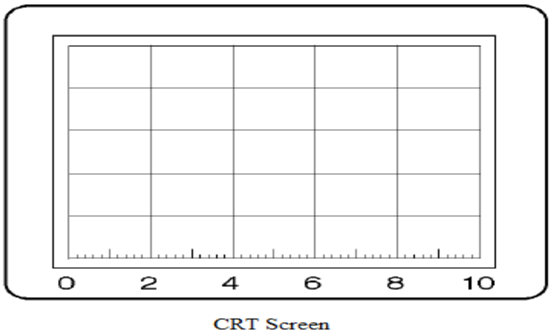


Figure 7.3g, Divisions on CRT Screen

$$\text{Echo position on CRT screen} = \frac{\text{echo distance}}{\text{big division}} + \frac{\text{remainder}}{\text{small division}}$$

For 0 – 150 mm range

One Big division = 150/10 = 15

One small division = 15/5 = 3

Facing 25R face of the V2 calibration block

1st echo position = 25/ 15 = 1 big division and, 10/3 ≈ 3 small divisions

2nd echo position = 100/15 = 6 big divisions and, 10/3 ≈ 3 small divisions

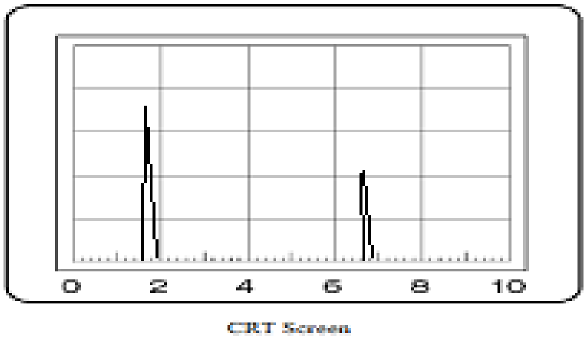


Figure 7.3h, Calibration of Range form 0-150mm by facing 25R Face

In this case 3rd echo cannot appear on CRT screen because that is out of range.

Example 2: Calibrate the range 0 – 150 mm by facing the 50R face of the V2 block.

For 0 – 150 mm range

One Big division = 150/10 = 15
One small division = 15/5 = 3

Facing 50R face of the V2 calibration block

1st echo position = 50/15 = 3 + 5/3 ≈ 3 + 2 = 3 big divisions + 2 small divisions
2nd echo position = 125/15 = 8 + 5/3 ≈ 8 + 2 = 8 big divisions + 2 small divisions

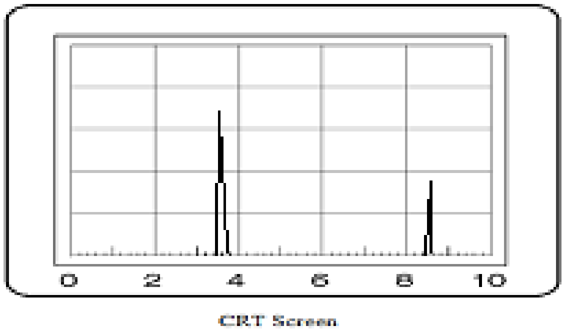


Figure 7.3i, Calibration of Range from 0-150mm by facing 50R Face

Example 3: Calibrate the range 0 – 225 mm by facing 50R face of the V2 block.

For 0 – 225 mm range-

One big division = 225/10 = 22.5 mm
One small division = 22.5/5 = 4.5 mm

Now facing 50R face of the V2 block

1st echo position = 50/22.5 = 2 + 5/4.5 ≈ 2 + 1 = 2 big divisions + 1 small division
2nd echo position = 125/22.5 = 5 + 12.5/4.5 ≈ 5 + 3 = 5 big divisions + 3 small divisions
3rd echo position = 200/22.5 = 8 + 20/4.5 ≈ 8 + 5 = 8 big divisions + 5 small divisions

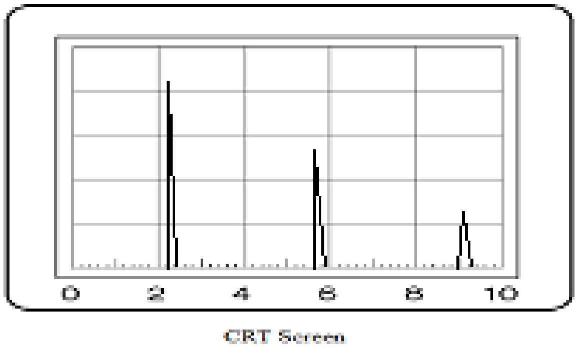


Figure 7.3j, Calibration of Range 0- 225mm facing 50R Face

7.4- Procedure for Making Distance Amplitude Correction (DAC) Curve:

For making a distance amplitude correction curve, first we need a reference block that must be made of same material and having same thickness as that of the workpiece to be tested [30].

- Usually in angle beam testing, DAC is generated using a specimen with side drilled holes.
- The size of the drilled hole is depends on the acceptance standard of the manufacturer.
- Generally the position of the hole is taken T/4, T/2 and, 3T/4. Where T is the thickness of the reference bock.
- The location of the holes must be in such a way that at a time, during testing, two holes never come in the path of sound beam.

Example: Make the DAC for 35mm thick block and 60° probe angle.
First take a reference block which must be of same material and same thickness as that of the specimen to be tested. Now make three holes at T/4, T/2 and, 3T/4 positions as shown in figure.

Figure 7.4a, Reference Block with Drilled Hole

In this figure, the drilled hole at T/2 position is not shown because that is drilled at just opposite face.

Step:1 Calculate half metal beam path(HMBP) and than calibrate the range.

$\text{HMBP} = T\sec\theta = 35\sec 60 = 70\text{mm}$

So, required range = 3×HMBP $= 3\times 70 = 210\text{mm} \approx 200\text{mm}$

Now for two echoes, make the range 0 – 200mm with V2 calibration block.
Facing 50R face of the V2 calibration block-

One big division = $200/10 = 20\text{mm}$
One small division = $20/5 = 4\text{mm}$

1st echo position = $50/20 = 2 + 10/4 \approx 2 + 2$ = 2 big divisions + 2 small divisions
2nd echo position = $125/20 = 6 + 5/4 \approx 6+1$ = 6 big divisions + 1 small division

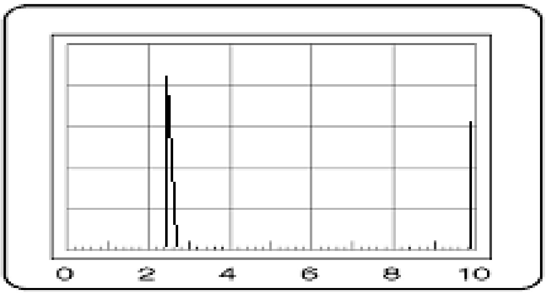


Figure 7.4b, Range Calibration from 0-200mm

Step: 2 After calibrating the range on CRT screen, take the hole which is located at 3T/4 position.

- For 3T/4 hole, calculate probe position (or half skip distance).

  Probe position $S_1 = \frac{3T}{4}\tan\theta = \frac{3\times35}{4}\tan60 = 45.47 \approx 45\text{mm}$

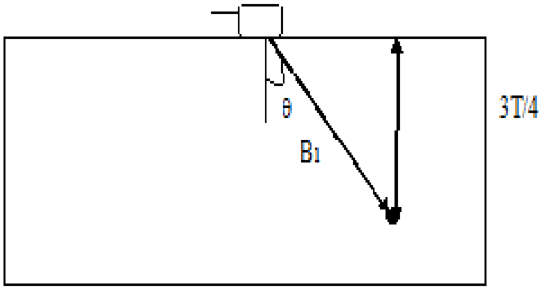


Figure7.4c, Reference Block with 3T/4 Hole Position

- Now calculate HMBP for above hole position.

  HMBP $B1 = \frac{3T}{4}\sec\theta = \frac{3\times35}{4}\sec60 = 52.5\text{mm} \approx 52\text{mm}$

- Calculate echo position for B_1

  Echo position $= 52/20 = 2 + 12/4 \approx 2 + 3$ = 2 big divisions + 3 small divisions.

- Now put the probe on the desired position and scan for maximum echo amplitude. As soon as you get maximum echo amplitude, mark a sign at the top of the echo on the CRT screen as shown in figure.

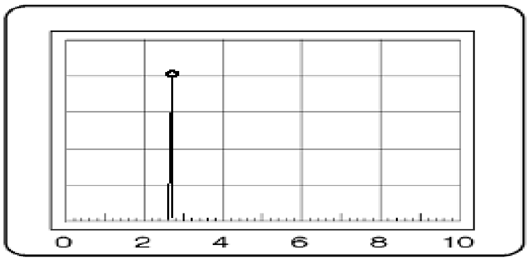


Figure 7.4d, Echo Position Corresponding to 3T/4 Hole Position

Step: 3 Now take the hole which is located at T/2 position.

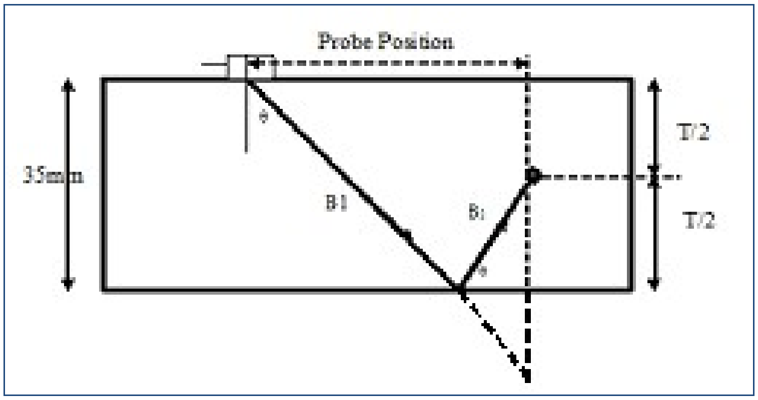


Figure 7.4e, Reference Block with T/2 Hole Position

- For T/2 hole, calculate metal beam path distance.

  $B_1 = T \times \sec\theta = 35\sec 60 = 35 \times 2 = 70\text{mm}$

  $B_2 = T/2 \times \sec\theta = 17.5 \times \sec 60 = 17.5 \times 2 = 35\text{mm}$

  Net metal beam path distance

  $B = B_1 + B_2 = 70 + 35 = 105\text{mm}$

- Probe position

  $S_2 = \text{net metal beam path} \times \sin\theta$

  $= 105 \times \sin 60 = 90.93\text{mm} \approx 91\text{mm}$

- Echo position

  1st echo position = 105/20

  $= 5 + 5/4 \approx 5 + 1 =$ 5 big divisions + 1small division

- Now put the probe on the desired position and scan for maximum echo amplitude. As soon as you get maximum echo amplitude, mark a sign at the top of the echo on the CRT screen as shown in figure.

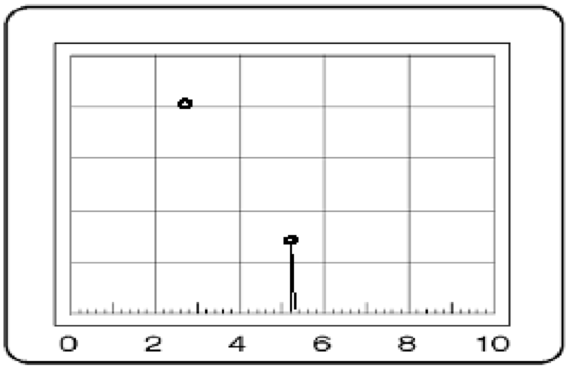


Figure 7.4f, Echo Position Corresponding to T/2 Hole Position

Step: 4 Now taking the hole which is located at T/4 position.

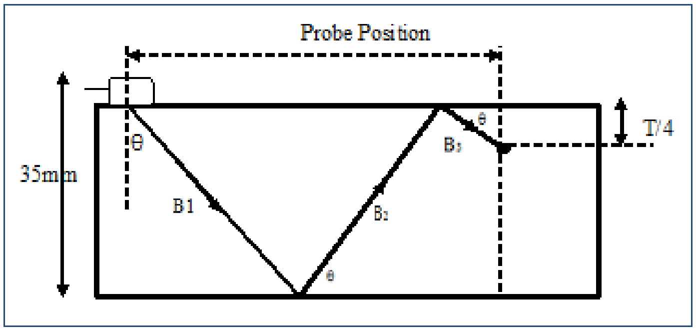


Figure 7.4g, Reference Block with T/4 Hole Position

- For T/4 hole, calculate metal beam path distance.

  Since $B_1 = B_2 = 70\text{mm}$

  $B_3 = T/4 \times \sec\theta = 8.75 \times \sec 60 = 15.5 \text{ mm}$

  Net metal beam path distance

  $B = B_1 + B_2 + B_3$

  $= 70 + 70 + 17.5$

  $= 157.5\text{mm}$

- Probe position

  $S_3 =$ net metal beam path distance $\times \sin\theta$

  $= 157.5 \times \sin 60$

  $\approx 136\text{mm}$

- Echo position

  1st echo position = 136/20 = 6 + 16/4 = 6 + 4 = 6 big divisions + 4 small division

- Now put the probe on the desired position and scan for maximum echo amplitude. As soon as you get maximum echo amplitude, mark a sign at the top of the echo on the CRT screen as shown in figure

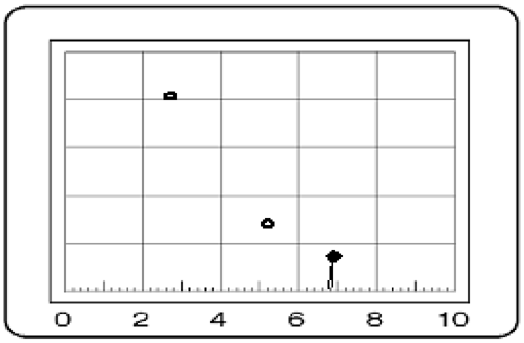


Figure 7.4h, Echo Position Corresponding to T/4 Hole Position

Resultant DAC Curve: Join all the points which are marked on the CRT screen. This gives required DAC curve. The defect is acceptable or not depends on its echo amplitude. If the amplitude of the defect echo is going beyond the DAC curve, its means that defect in not acceptable and vice versa.

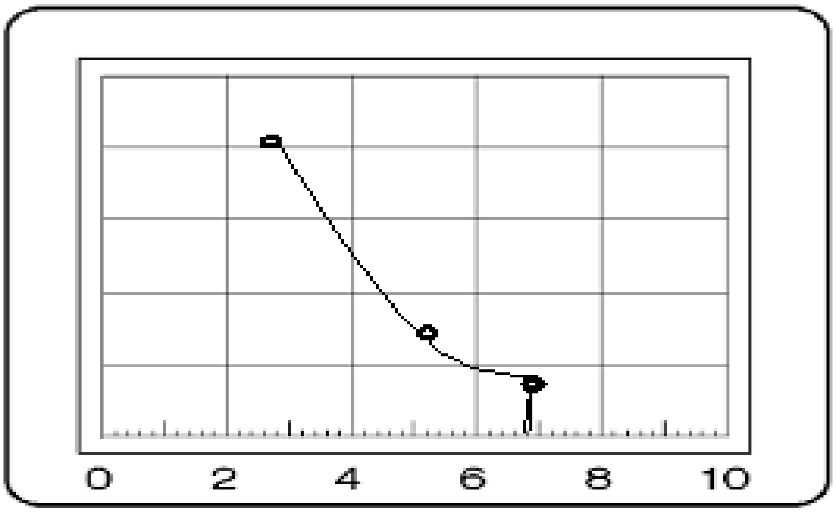


Figure 7.4i, Resultant DAC curve

Note- During making DAC curve, the gain level should be constant.

7.5- Calculation of the Probe Scanning Positions:

Since ultrasonic inspection of weld is carried out by shear waves which inters at certain angle in to the test specimen. So it is required to calculate probe position for proper inspection of weld [30].

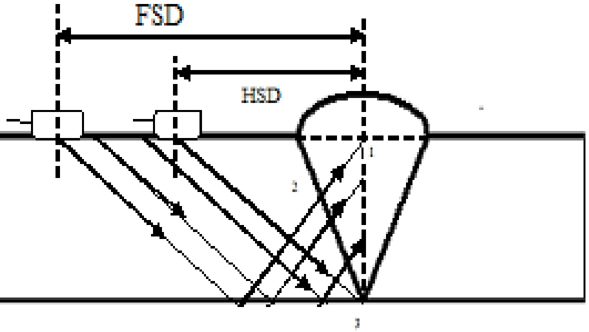


Figure 7.5a, Probe Scanning Between HSD and FSD

- Calculate half skip and full skip distance.

HSD = T×tanθ

FSD = 2T×tanθ

- Now perform scanning between the region FSD and HSD. Move the probe to and fro manner between FSD and HSD.
- Movement of the probe, in the region between FSD and HSD, are capable to inspect the weld area 1-2-3-1as shown in figure.

For inspection of remaining part of the weld, scan the probe between FSD and 1.5 FSD.

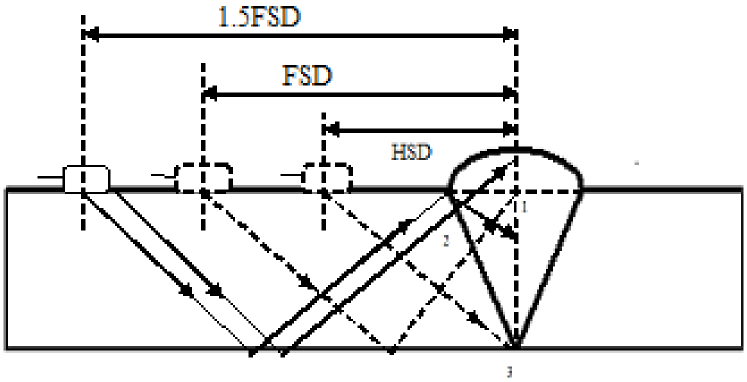


Figure 7.5b, Probe Scanning Between FSD and 1.5FSD

Perform same scanning procedure for remaining right hand side region of the weld. This gives complete inspection of the weld.

7.6- Determination of Defect Location:

The basis for defect location is the definite relationship between defect location and sound path. Determination of the depth of the probe and distance from the centre of the probe is needed for judging the nature of flaw on the basis of its position and thus its importance. The location of the defect can be calculated from the knowledge of the beam path length and the probe angle [30-31].

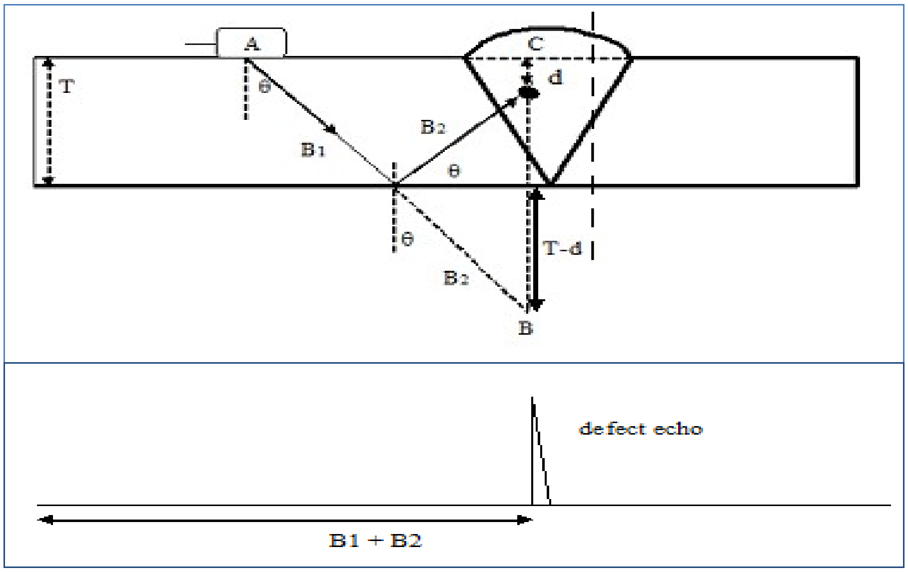


Figure 7.6, Calculation of Defect Location

Where B_1 and B_2 is metal beam path, θ is probe angle, T is thickness and d is the depth of the defect.

In Δ ABC $AB = B1 + B2 = B$ (say, can be read directly from CRT screen).

$BC = T - d + T = 2T - d$

Now $\cos\theta = \frac{BC}{AB} = \frac{(2T - d)}{B}$

Thus the depth of the defect $d = 2T - B\cos\theta$

The surface distance of the defect from the probe centre can be calculated as:

In ΔABC $\sin\theta = \frac{AC}{AB}$ or $AC = AB\sin\theta$

So surface distance of the defect $S = AC = B\sin\theta$

7.7- Defect Sizing:

The following methods are used for defect sizing-

- 6dB Drop Method
- 20dB Drop Method

6dB Drop Method: The 6-dB drop technique is the easiest technique for sizing large, planar defects. It is based on the basic assumption that when half of the ultrasonic beam is not reflected by a defect, the echo is 6 dB less than when the entire beam is reflected. It is then assumed that when half of the beam is returned, the transducer centerline is directly over the edge of the defect. Unfortunately, this only occurs in a defect with straight edges and only when the transducer is away from a defect corner. Because this type of defect very rarely occurs, the 6-dB technique only gives an approximation of the defect size. The following describes the general procedure [30]:

- Position the probe to get the maximum echo from the flaw.
- Adjust the height of the echo to some convenient scale on the CRT screen by using the gain control of the flaw detector.
- Move the probe across the flaw in one direction until the echo height reduces to1/2 (50%) of the height adjusted in second step.
- Mark the centre of the probe on the surface of the test specimen for this probe position.
- Now move the probe in opposite direction through the maximized echo position to the position when the echo height again reduces to 1/2 (50%) of the height adjusted in second step.
- Mark the position of the probe centre.
- Measure the distance between the two markings. The distance between the two marks gives the length of the defect parallel to the probe movement.

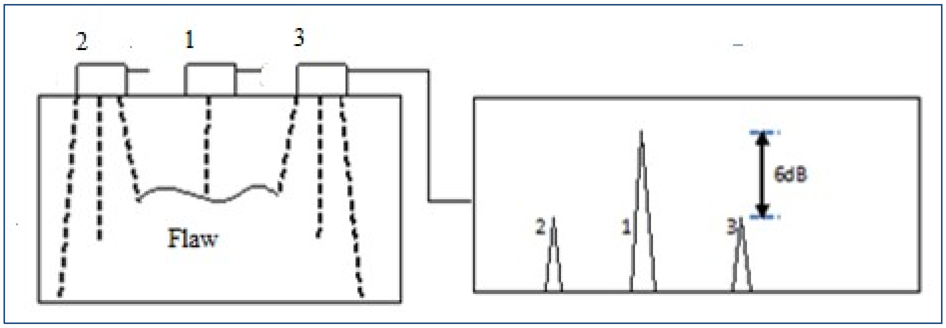


Figure 7.7, 6dB Defect Sizing Method

The 6dB drop method is suitable for the sizing of flaws which have sizes greater than that of the ultrasonic beam width. But this method will give inaccurate results when the flaws are smaller than the ultrasonic beam width.

20dB Drop Method: The 20-dB drop technique often is used to size small defects in welds using angle probes where the intensity falls to 10% (20dB) of the intensity at the center axis of the beam. The procedure is as follows [30]:

- Position the probe to get the maximum echo from the flaw.
- Adjust the height of the echo to some convenient scale on the CRT screen by using the gain control of the flaw detector.
- Move the probe across the flaw in one direction until the echo height reduces to 1/10th (20dB) of the height adjusted in second step.
- Mark the centre of the probe on the surface of the test specimen for this probe position.
- Now move the probe in opposite direction through the maximized echo position to the position when the echo height again reduces to 1/10 of the height adjusted in second step.
- Mark the centre of the probe on the surface of the test specimen for this probe position.
- Measure the distance between the two markings. The distance between the two marks gives the length of the defect parallel to the probe movement.

The 20dB drop method gives more accurate result than the 6dB drop method because of the greater control one has on the manipulation of the ultrasonic beam. However, size estimation using either 6dB or 20 dB drop method has inherent difficulties which must be considered. The main problem is that the amplitude may drop for reasons like tapered defect, surface roughness, or irregular defect etc.

7.8- Selection of the Parameters for Weld Inspection:

Selection of Test Frequencies: When setting up an ultrasonic program, one of the first considerations is the choice of frequency. It is usually desirable to test at the lowest frequency that will locate specified minimum sizes and types of discontinuity consistently. The minimum size of the defect which can be detected will be of order of $\lambda/2$ (where λ= wavelength). The sensitivity of the test increases with increase in frequency but depth of penetration of sound beam decreases. The effect of near zone and beam spread which varies with frequency should be considered. Due to this reason, an optimum frequency level is selected. For coarse grain material low frequency and for fine grain material high frequency is selected. For mild steel welds usually a frequency in the range of 1 MHz to 5 MHz will be satisfactory [31].

Selection of Probes: The most desirable probes for a given application are usually determined by experience. However, few rules can be applied for the selection of a probe.

- Maximum beam convergence and minimum number of scanning passes can be attained with large size probes. The difficulty in defining a small flaw in a large beam is also important. Limiting factors are test surface flatness and the minimum size of the flaw to be detected and located.
- A large diameter probe is usually used for testing higher thickness materials.
- Small diameter probe is used for testing small thickness materials.
- Beam spread is often desirable to pickup randomly oriented flaws. For a given frequency, beam spread is decreased with an increase of crystal diameter.

Selection of Probe Angle: The selection of probe angle depends on the thickness of the workpiece and the bevel angle of the weld geometry. A rule – of thumb, for determining the angle of probe to be used which is given as-

$$\text{Required probe angle } \theta = 90 - T$$

Or $= 90 - \beta$

Where T is the thickness of the specimen to be tested and β is the half bevel angle of the weld [31].

Selection of Velocity of Sound: Good knowledge of the velocity of the sound in the test material is important. In combination with the material density, it establishes the impedance of the material and the angle of refraction which the sound beam will take inside the material when it enters at an angle to the normal at the test surface. The following table gives the sound velocity in various materials [31].

Table 1: Ultrasonic Sound Velocity in Common Materials

Material	**Density (Kg/m3)**	**Transverse velocity (m/s)**	**Longitudinal velocity (m/s)**
Aluminium	2700	3130	6320
Aluminium oxide	3600	5500	9000
Brass	8100	2120	4430
Cast Iron	6900	2200	5300
Copper	8900	2260	4700
Grey Cast Iron	7200	2650	4600
Lead	1400	700	2160
Magnesium	1700	3050	5770
Nickel	8800	2960	5630
Perspex	1180	1430	2730
Steel	**7850**	**3290**	**5920**
Titanium	4540	3180	6230
Tungsten	19100	2620	5460
Uranium	18700	……….	3200
Water (20 deg C)	1000	………	1480
Zinc	7100	2410	4170

Other Parameters: To test the materials ultrasonically, the following parameters should be taken in to consideration-

- Acoustic attenuation

- Acoustic impedance
- Surface contour of the test material
- Surface roughness

The impedance ratio of the materials gives the proportion of power transmitted from one material to another material of different acoustic impedance i.e. the amount of energy transmitted in to the second material is a function of Z_2 / Z_1. The impedance ratio when sound beam enters from water to steel is about 30 and from water to aluminium is about 12. The portion of the sound energy which enters from water to steel is about 0.117 of the incident energy and from water to aluminium is about 0.267 [31].

Chapter: 8

Testing of the Weld Joints

8.1- Preparation of the Workpiece:

For welding the metal components we have using synergic MIG welding process. The synergic MIG welding process is a fusion welding process which utilizes the heat of an arc between a continuously fed electrode and the work piece to be welded. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the work piece where it becomes the deposited weld metal. Shielding of the weld pool is obtained from an envelope of gas, which may be an inert gas, an active gas, or a mixture. Shielding gas surrounds the weld pool to protect it from contamination from the atmosphere.

Figure 8.1a, Synergic MIG Welding Machine Setup

Details of weld preparation: For testing a weld ultrasonically, we have taken a single vee butt joint weld. The details are as shown in figure. The welding parameters are current 170A, Voltage 20V and travel speed 7mm/sec.

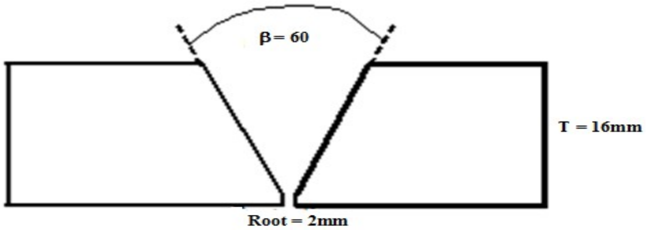


Figure 8.1b, Details of Workpiece Preparation

The details of the work pieces to be tested is as follows-

Material --Mild Steel
L×W×T = 150×150×16 mm

8.2- Testing Setup:

Krautkramer USM22 ultrasonic flaw detector is used for inspection of weld joint as shown in figure which can be operated by plug-in-power supply unit or with batteries.

Figure 8.2, Ultrasonic Flaw Detector

Connecting a probe: To prepare the USM22 for operation, you have to connect a probe to it. The probe is connected to the sockets at the top right on the instrument casing.

Setting the function: The functions of the USM22 are combined to form function groups on the two operating levels. The various functions of flaw detector are given in table2

Table2 Various Functions of USM22 flaw detector

Function Group	**Function**	
BASE	RANGE	You can adjust the range for your measurement by means of the right hand rotary knob.
	MTLVEL	You can set the sound velocity in the test object by means of right hand rotary knob.
	D- DELAY	In this you can choose whether to display the adjusted range starting from the surface of the test object or in a section of the test object starting at a latter point. This allows you to shift the complete screen display.
	P- DELAY	Every probe has a delay line between the transducer element and the coupling face. In this you can compensate the probe delay line.
P/R	DAMPING	Tthis fuction serves for matching the probe. You can use it to adjust the damping of the probe oscillating circuit and to change the height, width and resolution of the echo display
	POWER	This fuction allow you to adjust the intensity of the initial pulse
	REJECT	This function allow you to suppres unwanted echo indications.
	DUAL	You can activate the pulser – reciever sepration by this fuction. This function must be set off in pulse echo mode using single element probe.
GATE	aLOGIC	This function allow you to to choose the method for triggering the gate alarm.
	aSTART	This fuction allow you to fix the starting point of the gate A.
	aWIDTH	By this function you can determine the gate width.
	aTHRSH	This function allow you to determine the threshold value of the gate .
CFG	CONTR	
	LIGHT	
	PRINTER	
	DIALOG	

8.3 Testing of the Weld Joint:

Step: 1- Select Test Parameters: The selection of the testing parameters depends on the thickness of the workpiece to be tested, material of the workpiece and, weld geometry.

Table: 3 Test Parameters

Thickness of the workpiece (T)	Probe angle (dig)	Probe frequency	Sound velocity (shear wave)	couplant
16mm	70°	4 MHz	3290 m/s	Water

- Probe angle is selected on the basis of formula 90 –T.
- Since weld inspection is carried out with shear waves, so we selected shear velocity of the sound waves.
- The inspection of steel component is carried out within the frequency range 1-5 MHz, so we selected 4MHz frequency probe.

Step: 2- Determine the Probe Index: Probe index can be determined with the help of IIW (V1) calibration block. Place the probe on the IIW block in such a way that the beam is directed towards the you get maximum a spect to the centre o

Figure 8.3a, Measuring Probe Index

Step: 3- Determine the Probe Angle: The probe angle can be determined with the help of IIW (V1) calibration block and probe index. Place the probe on the angles side as marked on the calibration block facing 50mm diameter hole. Move the probe for maximum echo amplitude. As soon as we get an echo of maximum amplitude, stop the probe movement and compare the angle marked on the calibration block with the probe index point. The angle marked on the V1 block, corresponding to the probe index point, is the angle of the probe as shown in figure. The probe angle which we find during testing is 70°.

Figure 8.3b, Measuring Probe Angle

Step: 4- Calculation and Calibration of the Range: Weld inspection is carried out by angle beam probe so the required range for complete inspection can be calculated as:

- Calculate Half Metal Beam Path for given workpiece thickness and probe angle

$$\text{HMBP} = T \times \sec\theta$$

$$= 16\times\sec 70 = 46.7808\text{mm}$$

$$\textbf{Required Range} = \mathbf{3\times HMBP}$$

$$= 3\times 46.7808$$

$$= 140.34 \text{ mm}$$

- So, we taken range from 0 - 200 mm

Now 0- 200mm range can be calibrated with the help of both IIW (V1) and by IIW (V2) calibration block. We calibrated the range with the help of IIW (V1) calibration block by facing 100R face. In this case

1st echo distance = 100R (mm) and 2nd echo distance = 200R (mm)

Echo position on CRT screen

One big division = 200/10 = 20

One small division = 20/5 = 4

1st echo position on CRT = 100/20 = 5 big divisions

2nd echo position on CRT = 200/20 = 10 big divisions

The calibrated range is shown in figure

Figure 8.3c, Range Calibration from 0-200 mm

Step: 5- Calculate Probe Scanning Positions: Since ultrasonic inspection of weld is carried out by shear waves which inters at certain angle in to the test specimen. So it is required to calculate probe position for proper inspection of weld.

- Calculate half skip and full skip distance.

HSD = T×tanθ = 16×tan70 = 43.9596mm ≈ 44mm

FSD = 2T×tanθ = 2×16×tan70 = 87.92mm ≈ 88mm

n

- F

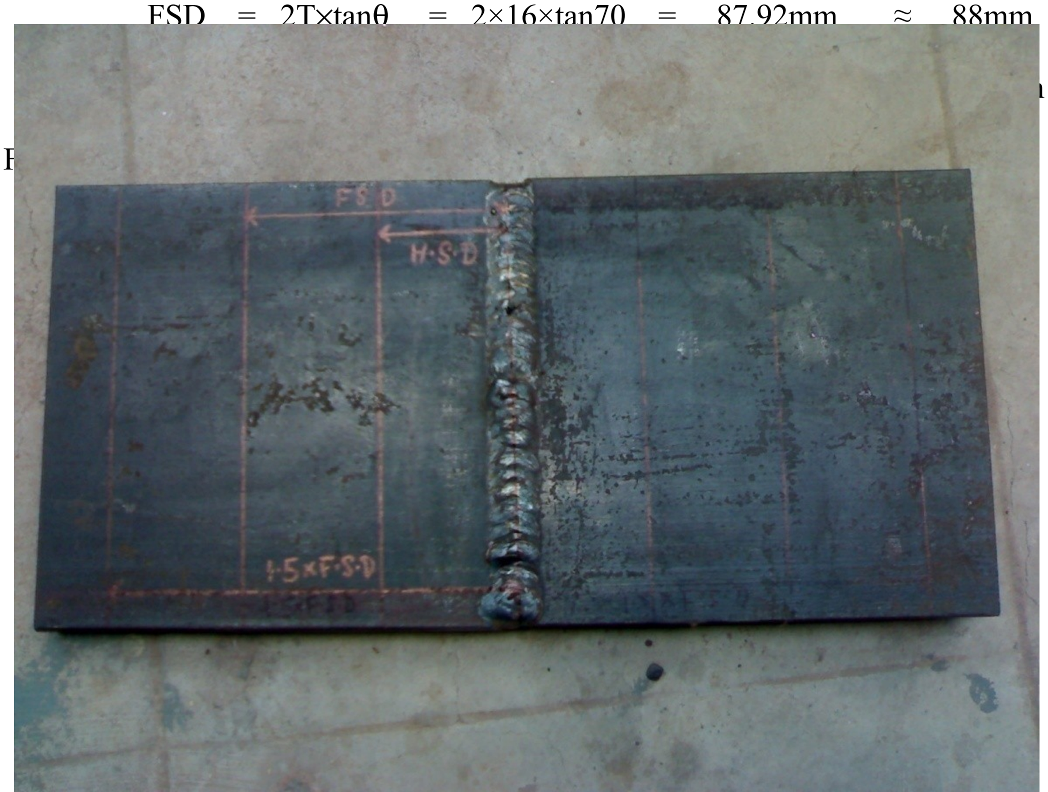


Figure 8.3d, Test Piece with Probe Scanning Positions

Step: 6 Testing of the Weld Piece: Apply the couplant and move the probe to and fro manner between HSD, FSD and 1.5FSD regions. You can inspect left half part of the weld by scanning between these two regions. For remaining right half part use same process. This gives complete inspection of the weld. If there is any defect in weld bead only than echo appears on the screen otherwise there is no echo. During testing we found three defects.

1st Defect:

Figure 8.3e, 1^{st} Defect Echo at CRT Screen

From figure we can see a defect echo on screen which appears at 15mm scale division. The depth of the defect can be calculated by using the formula (d = 2T – B ×cosθ). The depth is 14.90 mm. The surface distance of the defect from the centre of the probe can be calculated by using the formula (S = B× sinθ). The surface distance is 46.98 mm.

Figure 8.3f, Defect Free Weld Zone

2^{nd} Defect:

Figure 8.3g, 2^{nd} Defect Echo on CRT Screen

For 2nd defect, B = 18 mm scale division. So the depth is 12mm and surface distance from the probe centre is 56.38mm. This is an internal defect which may be a small crack or solid inclusion.

3rd Defect:

Figure 8.3h, 3rd Defect Echo on CRT Screen

For 3rd defect, B = 15mm scale division. So depth is approximately 15mm and surface distance from the probe centre is 47mm.

When Scanning is performed between FSD and 1.5FSD, we don't get any defect echo on screen.

Figure 8.3i, Scanning Between FSD and 1.5FSD

8.4- Result and Discussion:

During ultrasonic inspection of the weld joint we find three defects. Two of them are incomplete route penetration and one is internal defect that may be a crack or solid inclusion. The location of the defects is as follow:

1st Defect

Depth is14.90mm and surface distance from the centre of the probe is 46.98mm.

2nd Defect

Depth is 12.00mm and surface distance from the centre of the probe is 56.38mm.

3rd Defect

Depth is 15.00mm and surface distance from the centre of the probe is 47.00mm.

During ultrasonic inspection of the weld, sudden echo indication must not be taken as evidence of the defect. On the contrary, the origin of the echo should be sought by a number of tests from as many different directions as possible.

8.5- Recommendations:

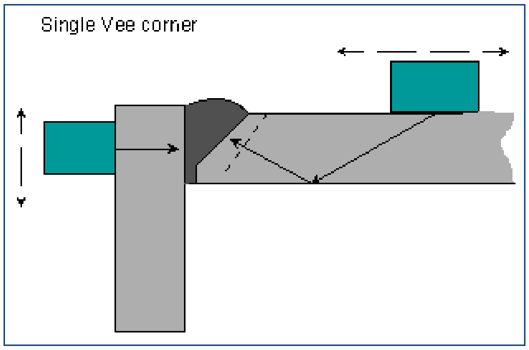
- Perform scanning from both sides of the weld with sufficient overlap to ensure complete coverage and with a swivel motion of the probe.
- Because of high attenuation and scattering of sound beam, steel welds gives very poor signal to noise ratio. So be careful at the time of selecting echo indication as an evidence of flaw.
- For testing of steel weld always select probe frequency in the range of 1MHz – 5 MHz's. Since as the frequency is increases, the test sensitivity increase but at the same time the attenuation of the sound energy also increases.
- The most desirable probe angle for inspection of steel weld is 45°, 60° and 70°.
- The minimum size of defect which can be detected by ultrasonic testing is $\lambda/2$, where λ is the wavelength. So always use as minimum as possible wavelength of ultrasonic waves.
- Always use high frequency probe for testing finer grain materials and low frequency probe for coarse grain materials.

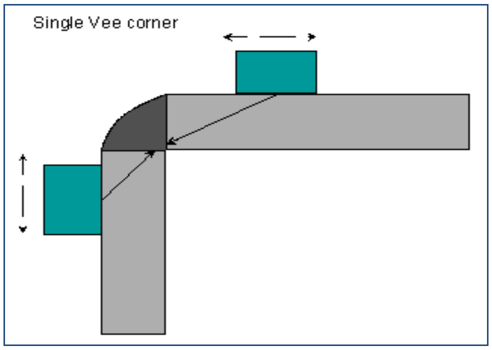
- The scanning surfaces should be sufficiently clean and free from irregularities like rust, loose scale, paint, weld spatter or grooves which may interfere with probe coupling.

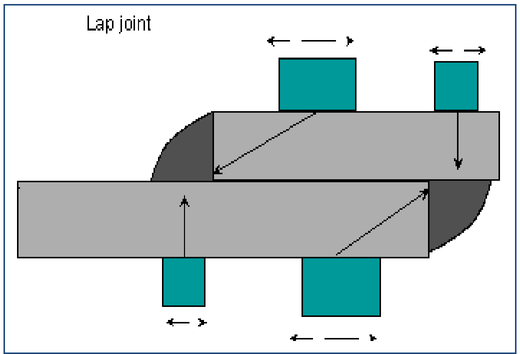
8.6- Scope of Future Work:

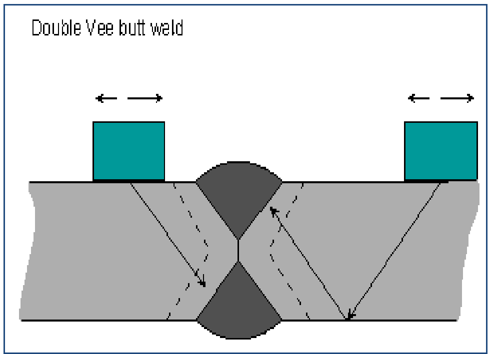
Many of the advances in NDT techniques have been driven by today's increasing pressures for cost-effective weld inspection. Cost effectiveness is linked to factors such as reliability, sensitivity, speed and coverage of NDT techniques. The need for greater reliability, speed and coverage has resulted in the increasing use of automated ultrasonic systems for weld inspection, particularly in the nuclear and pressure vessel industries and in a range of marine applications. Rapid development has occurred in a range of non-contact NDT techniques which should improve speed of inspection in the future, as will the continuing development of neural networks for automated data processing. Many challenges remain in NDT of welds, particularly in minimizing inspection costs without prejudicing structural integrity.

8.7- Ultrasonic Inspection of Other Weld Joints:









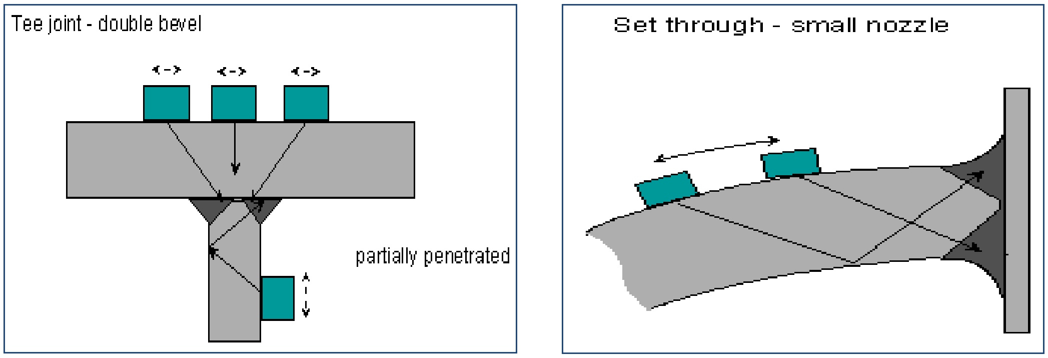


Figure 8.7, Ultrasonic Inspection of Other Weld Joints

8.8- Codes, Standard, Specifications and Procedures for Ultrasonic Inspection:

Code: Code is a comprehensive document relating to all aspects like design, material, fabrication, construction, erection, maintenance, quality control as well as documentation for specific Industrial sectors like pressure vessels, air craft, etc. Codes are prepared by the professional bodies or Government agencies in a specific subject. For NDT, the code should clearly specify when and what NDT techniques shall be applied, the intent of NDT and the acceptance criteria.

Standards: These are more specific documents giving the details of how a particular operation is to be carried out. These standards take in account the available technological levels and operational skills of the operators, in laying down the requirements of the standards. Standards are prepared by a body of professionals or a Government agency in a specific subject. These standards attempt to standardize material or activity. This avoids a multiplicity of procedures and duplication of efforts which is unprofitable and confusing.

Specifications: The document that prescribes in details, the requirements with which the product or service has to comply is the specification. The specification is of paramount importance in the achievement of quality. In many cases, poor products or services are the result of inadequate, ambiguous or improper specification. For a product to be manufactured and operated properly there will be different specifications like raw material specification, process specification, installation specification, maintenance specification etc.

Procedures: These are the lowest level documents for any process, service method etc. to be adopted in the shop- floor. The procedures are evaluated for each activity and confirm to the codes, standards and job specifications. Ultrasonic examination is required to be performed in accordance with a written procedure. The procedure shall be include at least the following information-

- Weld types, materials and configurations to be examined including thickness and dimensions.
- Surface conditions.
- Couplants, brand name or types.
- Technique of testing (straight beam, angle beam, contact or immersion).
- Angle and mode of wave propagation in the material.
- Probe type, frequency, and probe size.
- Type of ultrasonic instrument
- Description of calibration blocks.
- Data to be recorded and method of recording.
- Personnel qualification requirements.

Useful specifications related to ultrasonic testing:

Table: 4 ASTM Standards [30-31]

Code	Specification
E.113-74	Ultrasonic testing by resonance method.
E.114-75	Ultrasonic pulse echo straight beam testing by the contact method.
E.127-75	Fabricating and checking of aluminium alloy, ultrasonic reference block.
E.164-74	Ultrasonic contact examination of weldment.
E.213-77	Ultrasonic inspection of metal pipe and tubing for longitudinal discontinuities.
E.214-74	Immersion ultrasonic testing by the reflection method, using pulse longitudinal waves.
E.273-68	Ultrasonic inspection of longitudinal and spiral welds of welded pipes and tubing.
E.317-68	Evaluating performance characteristics of pulse echo ultrasonic testing system.
E.428-75	Fabrication and control of steel reference blocks used in ultrasonic inspection.
E.494-75	Measuring ultrasonic velocity in materials.
E.500-74	Definitions of terms relating to ultrasonic testing.
E.587-76	Ultrasonic angle beam examination by the contact method.
E.588-76	Detection of large inclusions in bearing quality steel by the ultrasonic method.

A:418-74	Ultrasonic testing and inspection of turbine and generator steel rotor forging.
A:435-75	Specification for straight beam ultrasonic examination of steel plates for pressure vessels.
A:531-74	Recommended practice for ultrasonic inspection of turbine generators steel retaining rings.
A:538-75	Specification for straight beam ultrasonic examination of plain and clad steel plates for special applications.
B:594-74	Ultrasonic inspection of aluminium alloy wroght product for aerospace specifications.
A609	Longitudinal beam ultrasonic inspection of carbon and low alloy steel castings.
A745	Ultrasonic examination of austenitic steel forgings.
B597	Test method for pulse velocity through concrete.
B2845	Test method for pulse velocities and ultrasonic elastic constants of rock.
D2966	Test method for cavitation erosion-corrosion characteristics of aluminium in engine coolants using ultrasonic energy.
E453	Recommended practice for examination of fuel element cladding including the determination of the mechanical properties.
E664	Measurement of the apparent attenuation of longitudinal ultrasonic waves by immersion testing method.
E797	Measuring thickness by manual ultrasonic pulse echo contact method.
E804	Calibration of an ultrasonic test system by extrapolation between flat-bottom hole sizes.
F600	Non-destructive ultrasonic evaluation of socket and butt joints of thermoplastic piping.
B509-77	Specification for supplementary requirements for nickel alloy plate for nuclear applications.
B510-77	Specification for supplementary requirements for nickel alloy rod and bar for nuclear applications
B513-77	Specification for supplementary requirements for nickel alloy seamless pipe and tube for nuclear applications.

8.9- About ISNT and ASNT

ISNT: The Indian Society for Nondestructive Testing, (ISNT) is the society for NDT professionals and practitioners. Since inception in 1972, it offers invaluable resources, information and linkages for industrial quality development and professional development to its members. The Objective of the Society is to promote the awareness of NDT Science and Technology through education, research and exchange of technical information within the country and internationally to its members and other professionals using NDT.

ASNT: The American Society for Nondestructive Testing, (ASNT) is the world's largest technical society for nondestructive testing (NDT) professionals. Through organization and membership, they provide a forum for exchange of NDT technical information; NDT educational materials and programs; and standards and services for the qualification and certification of NDT personnel. ASNT promotes the discipline of NDT as a profession and facilitates NDT research and technology applications.

References:

1. American Society for Non-Destructive Testing, www.asnt.org, accessed on Jan, 2009.
2. Hayes, Charles, “The ABC's of Nondestructive Weld Examination”, American Welding Society, NDT.net, vol.3, no.6, accessed on April,2009.
3. NDT Education and Resource Centre, “magnetic particle testing”, www.ndt-ed.org,accessed on Jan, 2009.
4. Le Bihan.Y, Pavo.J, Marchand.C, “Characterization of Small Cracks in Eddy Current Testing”, Eur. Phys. J. Appl. Phys. 43, pp 231–237 (2008).
5. Trimm Marvin, “An Overview of Nondestructive Evaluation Methods”, Savannah River Technology Center, vol.no.3, pp 17-31, (2003).
6. Baby Sony, Balasubramanian.T, Pardikar R.J, “Ultrasonic sizing of embedded vertical cracks in ferritic steel welds”, Journal Theoretical and Applied Fracture Mechanics, 40, pp 145–151(2003).

7. Komura Ichiro, Hirasawa Taiji, Nagai Satoshi, Takabayashi Jun-ichi, Naruse Katsuhiko, " Crack detection and sizing technique by ultrasonic and electromagnetic methods", Journal of Nuclear Engineering and Design, 206, pp 351–362 (2001).
8. Arone M, Cerniglia D, Nigrelli D.V, "Defect characterization in Al welded joints by non-contact Lamb wave technique", Journal of Materials Processing Technology 176, pp 95–101(2006).
9. Edwards S.R, Dixon S, Jian X, "Characterization of defects in the railhead using ultrasonic surface waves", NDT&E International 39, pp 468–475 (2006).
10. Chen Tianlu, Que Peiwen, Zhang Oi, Liu Qingkun, "Ultrasonic Nondestructive Testing Accurate Sizing and Locating Technique Based on Time-of-Flight-Diffraction Method", Russian Journal of Nondestructive Testing, Vol. 41, No. 9, pp. 594–601 (2005).
11. Bullough R, Dolby E.R, Beardsmore W.D, Burdekin F.M, Schneider A.R.C, "The probability of formation and detection of large flaws in welds", International Journal of Pressure Vessels and Piping 84, pp 730–738 (2007).
12. Kyu PARK Seung, Moo CHEONG Yong, Hoon BAIK Sung, Ki CHA Hyung, Hoon LEE Sung, June KANG Young, "Detection of a Surface-Breaking Crack Depth by Using the Surface Waves of Multiple Laser Beams", 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China.
13. Riahi M, Abolhasany M.R, "Substitution of the Time-of-Flight Diffraction Technique for Nondestructive Testing of Welds and Thick Layers of Steel", Russian Journal of Nondestructive Testing, Vol. 42, No. 12, pp. 794–801(2006).
14. Bazulin G.E, "Imaging of Flaws with Allowance for Multiple Reflections of Ultrasonic Pulses from Plane–Parallel Boundaries of a Tested Object", Russian Journal of Nondestructive Testing, 2007, Vol. 43, No. 7, pp. 456–473.
15. Messer B, Patrick C, Seitz S, "Achieving cost savings with innovative welding and examination techniques", International Journal of Pressure Vessels and Piping 83 (2006) 365–372.
16. JIAN Xiaoming, DIXON Steve, QUIRK Karl, "Electromagnetic Acoustic Transducers for In and Out of plane Ultrasonic Wave Detection", 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China.
17. Jin Song Sung, Joon Kim Hak, Cho Hyeon, "Development of an intelligent system for ultrasonic flaw classification in weldments", Journal of Nuclear Engineering and Design 212 (2002) 307–320.
18. Baskarana G, Balasubramaniam Krishnan, Lakshmana Rao C, "Shear-wave time of flight diffraction (S-TOFD) technique", NDT&E International 39 (2006) 458–467.
19. Satyanarayan L, Sridhar C, Krishnamurthy C.V, Balasubramaniam Krishnan, "Simulation of ultrasonic phased array technique for imaging and sizing of defects using longitudinal waves", International Journal of Pressure Vessels and Piping 84 (2007) 716–729.

20. LOPEZ Borja, “Weld Inspection with EMAT Using Guided Waves”, NDT.net - The e-Journal of Nondestructive Testing (May 2008).
21. Grün Gerhard, “Considerations about ultrasonic inspection of welded joints using phased array”, 5th Int. Conference Structural Integrity of Welded Structures, Timisora, Romania, 20-21 Nov 2007.
22. Kemnitz P, Richter P.U, Kluber H, “Measurements of the acoustic field on austenitic welds: a way to higher reliability in ultrasonic tests”, Journal of Nuclear Engineering and Design 174 (1997) 259–272.
23. Giller G.A, Mogil'ner L.Yu, “Ultrasonic Testing of Welded Joints in Pipelines. New Techniques and Instruments”, Russian Journal of Nondestructive Testing, Vol. 36, No. I, 2000, pp. 64—67.
24. Lhe´mery A, Calmon P, Lecoeur-Taı¨bi I, Raillon R, Paradis L, “Modeling tools for ultrasonic inspection of welds”, NDT&E International 33 (2000) 499–513.
25. Margrave F.W, Rigas K, Bradley D.A, Barrowcliffe P, “The use of neural networks in ultrasonic flaw detection” Journal of Measurement 25 (1999) 143–154.
26. Baishya Chandra, Saxena B.K, “Ultrasonic in Railways”, Research Design and Standards Organization, Lucknow India, 2008.
27. NDT Education and Resource Centre, Introduction to Ultrasonic Testing, www.ndt-ed.org, accessed on March, 2009.
28. Krautkramer, “Nondestructive Material Testing with Ultrasonics”, NDT.net, Vol. 5 No. 09.
29. Parmar R.S, “Welding Engineering and Technology”, Khanna Publishers, pp 659-700 (2007).
30. Subramanian C.V, “Practical Ultrasonics”, Narosa Publishers, pp 98-128, (2008).
31. Mukhergy, “Training Course on Ultrasonic Testing- ASNT Level-II”, IRC Engineering Service Private Limited, New Delhi, India.
32. Ginzel E.A, “Weld Inspection of Ultrasonic Inspection 2- Training for Nondestructive Testing”, NDT.net, vol.3, no.4.
33. Barkhatov V.A, “Development of Methods of Ultrasonic Nondestructive Testing of Welded Joints”, Russian Journal of Nondestructive Testing, Vol. 39, No. 1, 2003, pp. 23–47.
34. Ushakov V.M, Davydov D.M, “Calibration Blocks for Ultrasonic Nondestructive Testing”, Russian Journal of Nondestructive Testing, 2006, Vol. 42, No. 3, pp. 149–155.
35. Ermolov I.N, “Progress in the Theory of Ultrasonic Flaw Detection. Problems and Prospects”, Russian Journal of Nondestructive Testing, Vol. 40, No. 10, 2004, pp. 655–678.
36. Senyutkin P.A, Chineikina E.F, “Estimating the Characteristics of Piezoelectric Transducers”, Russian Journal of Nondestructive Testing, Vol. 41, No. 1, 2005, pp. 14–20.

37. Ermolov I.N, “Achievements in Ultrasonic Inspection”, Russian Journal of Nondestructive Testing, Vol. 41, No. 8, 2005, pp. 483–489.
38. Ushakov V.M, “Principles of the Development of Piezoelectric Transducers for Ultrasonic Testing of Articles with Flat and Curvilinear Surfaces”, Russian Journal of Nondestructive Testing, Vol. 41, No. 6, 2005, pp. 355–361.
39. Shcherbinskii V.G, “How Ultrasonic Nondestructive Testing of Welded Joints Gained Its Independence”, Russian Journal of Nondestructive Testing, Vol. 41, No. 6, 2005, pp. 408–410.
40. Ditchburn R.J, Burke S.K, Scala C.M, “NDT of welds: state of the art”, NDT&E International, Vol. 29, No. 2, pp. 11 l-l 17, 1996
41. Yi Won, Yun In-Sik, “The Defect Detection and Non-Destructive Evaluation in Weld Zone of Austenitic Stainless Steel 304 Using Neural Network-Ultrasonic Wave”, KSME International Journal, VoL 12, No. 6 pP. 1150--1161, 1998.
42. Ermolov I. N, “Most Interesting Branches of the Development of Ultrasonic Testing of Metals”, Russian Journal of Nondestructive Testing, Vol. 39, No. 2, 2003, pp. 145–169.
43. Ushakov V. M, “Principles of the Development of Piezoelectric Transducers for Ultrasonic Testing of Articles with Flat and Curvilinear”, Russian Journal of Nondestructive Testing, Vol. 41, No. 6, 2005, pp. 355–361.
44. Ermolov I. N, “Progress in the Theory of Ultrasonic Flaw Detection Problems and Prospects”, Russian Journal of Nondestructive Testing, Vol. 40, No. 10, 2004, pp. 655–678.
45. Ushakov V. M, Mikhalev V. V, “Some Aspects of Using Piezoelectric Probes for Ultrasonic Inspection of Thin Welded Joints”, Russian Journal of Nondestructive Testing, 2007, Vol. 43, No. 3, pp. 204–209.