DEFECT DETECTION ON WELDED JOINTS USING ULTRASONIC TESTING

A project

Submitted in the partial fulfilment of the requirements for the Award of the Degree of

BACHELOR OF TECHNOLOGY

In

DEPARTMENT OF MECHANICAL ENGINEERING

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DECLERATION

The Project entitled **"DEFECT DETECTION ON WELDED JOINTS USING ULTRASONIC TESTING"** is a record of bonafied work carried out by us, submitted in partial fulfillment for the award of B. Tech in MECHANICAL ENGINEERING to the Jawaharlal Nehru Technological University Kakinada, Kakinada. This report has not been submitted to anyotherUniversity or Institute for the award of any degree or diploma.

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CERTIFICATE

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The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Product quality has always been one of the most important aspects of manufacturing operation. In present global economy and competition, continuous improvement in quality has become a major priority for various industrialized countries including India. In this percept Non-destructive evaluation is a wide and interdisciplinary field used to detect and verify the quality of products.

By using various Non-Destructive Evaluation Techniques internal defects are tested in such a manner that product integrity and surface texture remains unchanged. In the present study, a test specimen of HOT ROLLED MILD STEEL PLATE is taken to identify the discontinuities like Welding defects, Inclusions, edge cuttings, cracks, etc., by Ultrasonic FlaDetector using INCLINED BEAM PROBE.

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CHAPTER 1

INTRODUCTION

Importance of NDT

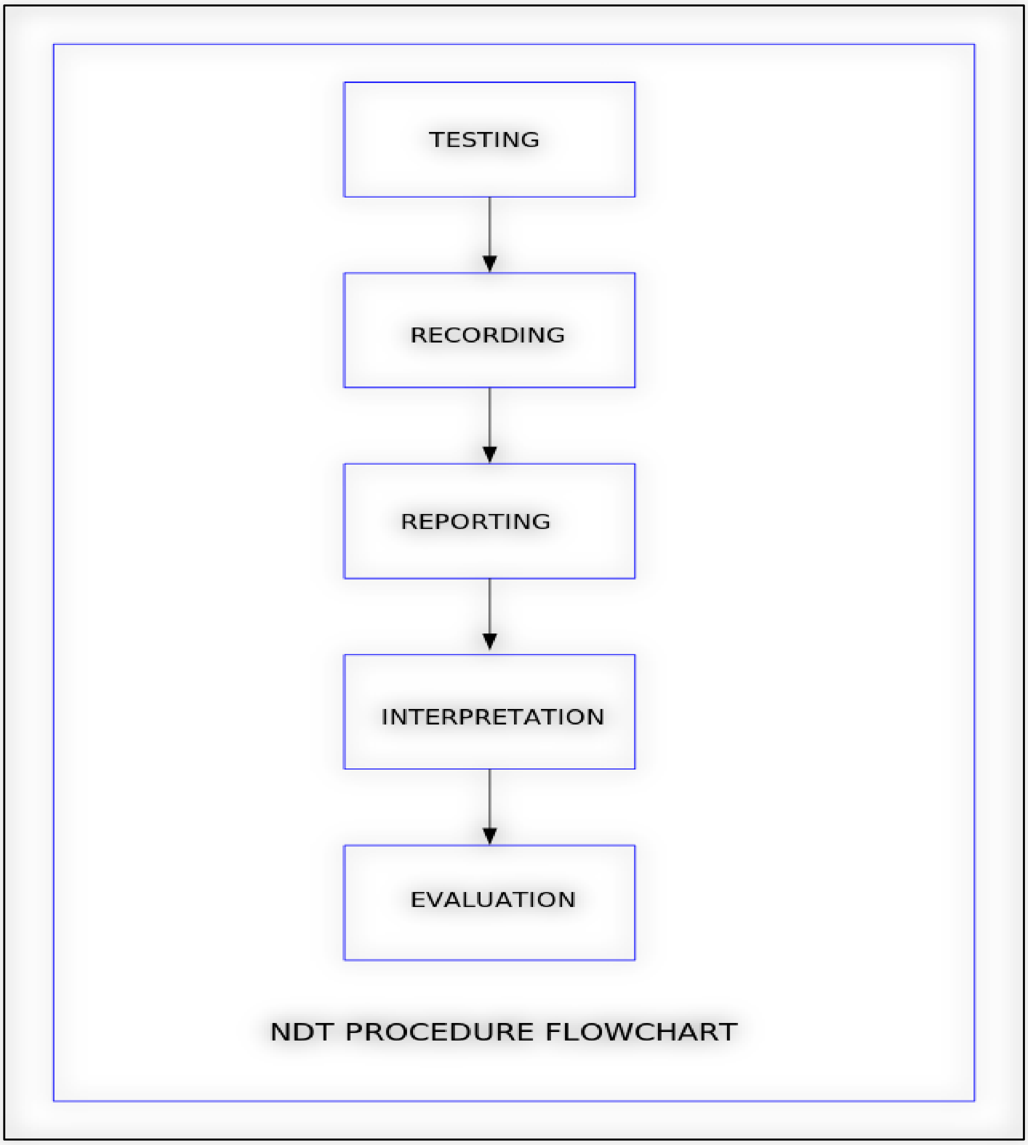


Fig1 : important of NDT

NDT plays an important role in the quality control of a product. It is used during all the stages of manufacturing of a product. It is used to monitor the quality of the:

(a) Raw materials which are used in the construction of the product.

(b) Fabrication processes which are used to manufacture the product.

(c) Finished product before it is put into service.

Use of NDT during all stages of manufacturing results in the following benefits:

(a) Increases the safety and reliability of the product during operation.

(b) Decreases the cost of the product by reducing scrap and conserving materials, labour and energy.

(c) It enhances the reputation of the manufacturer as producer of quality goods.

All of the above factors boost the sales of the product which bring more economical benefits to the manufacturer.

NDT is also used widely for routine or periodic determination of quality of the plants and Structures during service. This not only increases the safety of operation but also eliminates any forced shut down of the plants.

Types of NDT methods

0The methods of NDT range from the simple to the complicated. Visual inspection is the simplest ofall. Surface imperfections invisible to the eye may be revealed by penetrant or magnetic methods. If really serious surface defects are found, there is often little point in proceeding to more complicated examinations of the interior by ultrasonic or radiography. NDT methods may be divided into groups for the purposes of these notes: conventional and nonconventional.

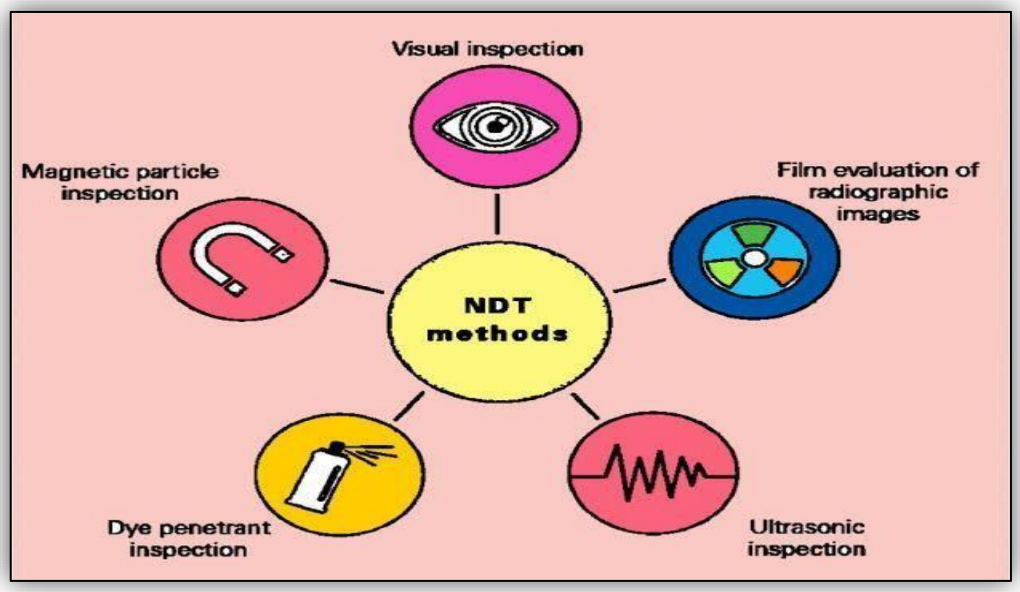


Fig 2: Types of NDT methods

VISUAL TESTING (VT)

Often overlooked in any listing of NDT methods, visual inspection is one of the most common and most powerful means of non-destructive testing. Visual testing requires adequate illumination of the test surface and proper eye-sight of the tester. To be most effective visual inspection does however, merit special attention because it requires training (knowledge of product and process, anticipated service conditions, acceptance criteria, record keeping, for example) and it has its own range of equipment and instrumentation. It is also a fact that all defects found by other NDT methods ultimately must be substantiated by visual inspection.

FILM EVALUATION OF RADIOGRAPHIC IMAGE

Systematic radiographic technical evaluation is an important aspect to evaluative, effective radiography. It is the process of assessing a radiographic image to ensure it meets a high level of diagnostic standard. Two mnemonics are commonly used when assessing a radiographic image: PACEMAN.

ULTRASONIC INSPECTION

Ultrasonic inspection is a non-destructive testing method that uses high-frequency sound waves to evaluate the internal structure of materials. It can be used for flaw detection, dimensional measurements, and material characterization.

DYE PENETRATION INSPECTION

Dye Penetrant Inspection (DPI) is a non-destructive testing method used to detect surface flaws in a wide range of materials. It's also known as liquid penetrant inspection (LPI) or penetrant testing (PT).

MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection (MPI) is a non-destructive testing method that detects surface and subsurface flaws in ferromagnetic materials. Ferromagnetic materials include iron, nickel, cobalt, and some of their alloys.

LIQUID PENETRANT TESTING

Liquid penetrate testing is one of the oldest and simplest NDT methods where its earliest versions (using kerosene and oil mixture) date back to the 19th century. This method is used to reveal surface discontinuities by bleed out of a coloured or fluorescent dye from the flaw. The technique is based on the ability of a liquid to be drawn into a "clean" surface discontinuity by capillary action. After a period of time called the "dwell time", excess surface penetrant is removed and a developer applied. This acts as a blotter that draws the penetrant from the discontinuity to reveal its presence.

It improves the detestability of a flaw due to the high level of contrast between the indication and the background which helps to make the indication more easily seen (such as a red indication on a white background for visible penetrant or a penetrant that glows under ultraviolet light for fluorescent penetrant.

Liquid penetrant testing is one of the most widely used NDT methods. Its popularity can be attributed to two main factors: its relative ease of use and its flexibility. It can be used to inspect almost any material provided that its surface is not extremely rough or porous. Materials that are commonly inspected using this method include, metals, glass, many ceramic materials, rubber and plastics. However, liquid penetrant testing can only be used to inspect for flaws that break the surface of the sample (such as surface cracks, porosity, laps, seams, lack of fusion, etc.

STEPS IN PENETRATION TESTING

PRE-CLEANING
APPLYING PENETRANT
DWELL TIME
REMOVABLE OF EXCESS PENETRANT
APPLYING DEVELOPER
DEVELOPING TIME
INTERPRETATION
POST CLEANING

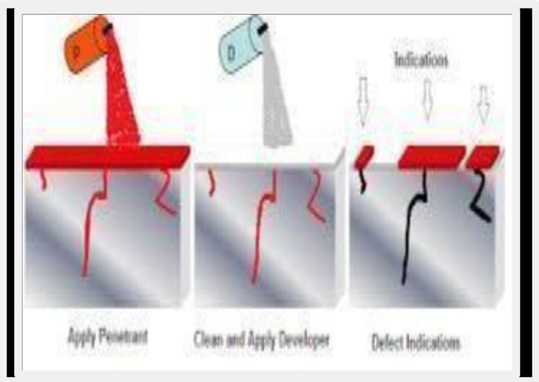


Fig 3: Liquid Penetration Test

MAGNETIC PARTICLE TESTING(MPT)

Magnetic particle testing is one of the most widely utilized NDT methods since it is fast and relatively easy to apply and part surface preparation is not as critical as it is for some other methods. This method uses magnetic fields and small magnetic particles to detect flaws in components. The only requirement from an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such as iron, nickel, cobalt, or some of their alloys.

The method is used to inspect a variety of product forms including castings, forgings, and weldments. Many different industries use magnetic particle inspection such as structural steel, automotive, petrochemical, power generation, and aerospace industries. Underwater inspection is another area where magnetic particle inspection may be used to test items such as offshore structures and underwater pipelines. Basic principle "Magnetic Flux Leakage".

STEPS IN MPT

PRE-CLEANING

DEMAGNETIZATION (If required)

APPLYING WHITE CONTRAST

MAGNETIZING THE MATERIAL

APPLYING MAGNETIC MEDIUM

INTERPRETATION

DE MAGNETIZATION

POST CLEANING

Fig 4: Permanent Magnet

ULTRASONIC TESTING

Ultrasonic Testing (UT) uses high frequency sound waves (typically in the range between 05 and 15 MHz) to conduct examinations and make measurements. Besides its wide use in engineering applications (such as flaw detection/evaluation, dimensional measurements, material characterization, etc.), ultrasonic are also used in the medical field (such as sonography, therapeutic ultrasound, etc.).

In general, ultrasonic testing is based on the capture and quantification of either the reflected waves (pulse-echo) or the transmitted waves (through-transmission). Each of the two types is used in certain applications, but generally, pulse echo systems.

Fig 5: Specimen Scanning

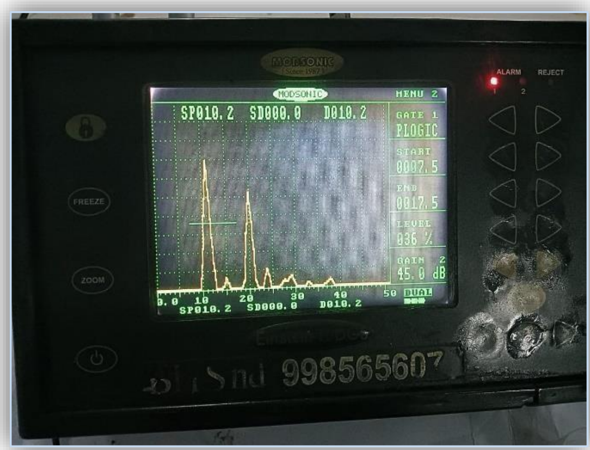


Fig 6: Defect Indication

Basic principle "Acoustic Impedance Mismatch"

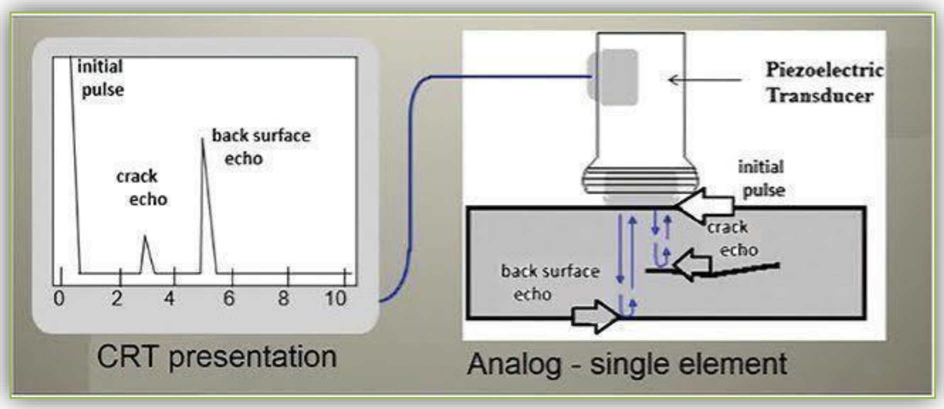


Fig 7: Ultrasonic Testing

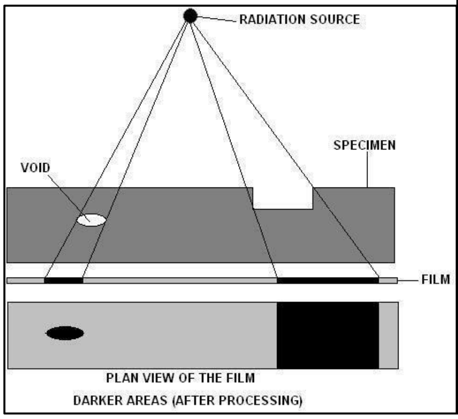
A typical pulse-echo UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and a display device. A pulser/receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic 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. Knowing the velocity of the waves, travel time can be directly related to the distance that the signal travelled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

RADIOGRAPHIC TESTING

Radiography is used in a very wide range of applications including medicine engineering, forensics, security, etc. In NDT, radiography is one of the most important and widely used methods. Radiographic testing (RT) offers a number of advantages over other NDT methods, however, one of its major disadvantages is the health risk associated with the radiation.

In general, RT is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by radiation sensitive film (Film Radiography) or by a planer array of radiation sensitive sensors (Real-time Radiography). Film radiography is the oldest approach, yet it is still the most widely used in NDT.



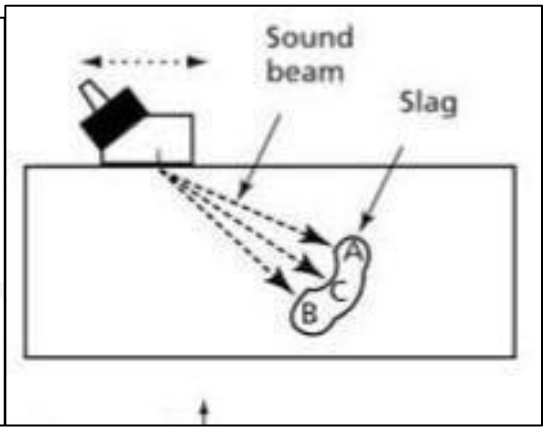


Fig 8: Radiographic Scanning **Fig 9: Cracks Detected in Material**

INTRODUCTION TO ULTRASONIC TESTING

Ultrasonic examination is a non-destructive method in which beams of high-frequency sound waves are introduced into materials for the detection of surface and subsurface flaws in the material. The sound waves travel through the material with some attendant loss of energy (attenuation) and are reflected at interfaces. The reflected beam is displayed and then analysed to define the presence and location of flaws or discontinuities.

The degree of reflection depends largely on the physical state of the materials forming the interface and to a lesser extent on the specific physical properties of the material. For example, sound waves are almost completely reflected at metal/gas interfaces. Partial reflection occurs at metal/liquid or metal/solid interfaces, with the specific percentage of reflected energy depending mainly on the ratios of certain properties of the material on opposing sides of the interface.

Cracks, laminations, shrinkage cavities, bursts, flakes, pores, and other discontinuities that produce reflective interfaces can be easily detected. Inclusions and other in homogeneities can also be detected by causing partial reflection or scattering of the ultrasonic waves or by producing some other detectable effect on the ultrasonic waves. Most ultrasonic inspection instruments detect flaws by monitoring one or more of the following:

- Reflection of sound from interfaces consisting of material boundaries or discontinuities within the metal itself
- Time of transit of a sound wave through the test piece from the entrance point at the transducer to the exit point at the transducer.
- Attenuation of sound waves by absorption and scattering within the test piece.
- Features in the spectral response for either a transmitted or a reflected signal.

Most ultrasonic inspection is done at frequencies between 0.1 and 25 MHz-well above the range of human hearing, which is about 20 Hz to 20 kHz. Ultrasonic waves are mechanical vibrations; the amplitudes of vibrations in metal parts being ultrasonically inspected impose stresses well below the elastic limit, thus preventing permanent effects on the parts. Many of the characteristics described in this article for ultrasonic waves. especially in the section "General Characteristics of Ultrasonic Waves," also apply to audible sound waves and to wave motion in general.

Ultrasonic inspection is one of the most widely used methods of non-destructive inspection. Its primary application in the inspection of metals is the detection and characterization of internal flaws, it is also used to detect surface flaws, to define bond characteristics, to measure the thickness and extent of corrosion, and (much less frequently) to determine physical properties, structure, grain size, and elastic constants.

BASIC EQUIPMENT

Most ultrasonic inspection systems include the following basic equipment:

- An electronic signal generator that produces bursts of alternating voltage (a negative spike or a square wave) when electronically triggered.
- Atransducer (probe or search unit) that emits a beam of ultrasonic waves when bursts of alternating voltage are applied to it.
- A couplet to transfer energy in the beam of ultrasonic waves to the test piece.
- A couplet to transfer the output of ultrasonic waves (acoustic energy) from the test piece to the transducer.
- A transducer (can be the same as the transducer initiating the sound or it can be a separate one) to accept and convert the output of ultrasonic waves from the test piece to corresponding bursts of alternating voltage. In most systems, a single transducer alternately acts as sender and receiver.
- An electronic device to amplify and, if necessary, demodulate or otherwise modify the signals from the transducer.
- A display or indicating device to characterize or record the output from the test piece. The display device may be a CRT, sometimes referred to as an oscilloscope: a chart or strip recorder, a marker, indicator, or alarm device; or a computer printout.
- An electronic clock, or timer, to control the operation of the various components of the system, to serve as a primary reference point, and to provide coordination for the entire system.

CIRCUITS

Electronic Equipment

Although the electronic equipment used for ultrasonic inspection can vary greatly in detail among equipment manufacturers, all general-purpose units consist of a power supply, a pulser circuit, a search unit, a receiver-amplifier circuit, an oscilloscope, and an electronic clock.

Many systems also include electronic equipment for signal conditioning, gating, automatic interpretation, and integration with a mechanical or electronic scanning system. Moreover, advances in microprocessor technology have extended the data acquisition and signal-processing capabilities of ultrasonic inspection systems.

Power Supply

Circuits that supply current for all functions of the instrument constitute the power supply, which is usually energized by conventional 115-V or 230-V alternating current. There are, however, many types and sizes of portable instruments for which the power is supplied by batteries contained in the unit.

Pulser Circuit

When electronically triggered, the pulser circuit generates a burst of alternating voltage The principal frequency of this burst, its duration, the profile of the envelope of the burst, and the burst repetition rate may be either fixed or adjustable, depending on the flexibility of the unit.

Search Units

The transducer is the basic part of any search unit. A sending transducer is one to which the voltage burst is applied, and it mechanically vibrates in response to the applied voltage. When

appropriately coupled to an elastic medium, the transducer thus serves to launch ultrasonic waves into the material being inspected.

A receiving transducer converts the ultrasonic waves that impinge on it into a corresponding alternating voltage. In the pitch-catch mode, the transmitting and receiving transducers are separate units; in the pulse-echo mode, a single transducer alternately serves both functions. The various types of search units are discussed later in this article.

Control Systems

Even though the nomenclature used by different instrument manufacturers may vary, certain controls are required for the basic functions of any ultrasonic instrument. These functions include power supply, clock, pulser, receiver-amplifier, and display. In most cases, the entire electronic assembly, including the controls, is contained in one instrument. A typical pulse-echo instrument is shown in Fig.

Fig 10: Flaw Detector

The power supply is usually controlled by switches and fuses. Time delays can be incorporated into the system to protect circuit elements during warm-up. The pulses of ultrasonic energy transmitted into the test piece are adjusted by controls for pulse-repetition rate, pulse length, and pulse tuning. A selector for a range of operating frequencies is usually labelled "frequency," with the available frequencies given in megahertz.

For single-transducer inspection, transmitting and receiving circuits are connected to one jack, which is connected to a single transducer. For double-transducer inspection, such as through transmission or pitch-catch inspection, a T (transmit) jack is provided to permit connecting one transducer for use as a transmitter, and an R (receive) jack is provided for the use of another Tran shaver for receiving only. A selector switch (test switch) for through (pitch catch) or normal (pulse echo) transmission is provided for control of the T and R jacks.

Gain controls for the receiver amplifier circuit usually consist of fine and coarse- sensitivity selectors or one control marked "sensitivity." For a clean video display, with low-level electronic noise eliminated, a reject control can be provided.

The display (oscilloscope) controls are usually screwdriver adjusted, with the exception of the scale illumination and power on/off. After initial setup and collaboration, the screwdriver-adjusted controls seldom require additional adjustment. The controls and their functions for the display unit usually consist of the following:

- Controls for vertical position of the display on the oscilloscope screen.
- Controls for horizontal position of display on the oscilloscope screen.
- Controls for brightness of display.
- Control for adjusting focus of trace on the oscilloscope screen.

- Controls to correct for distortion or astigmatism that may be introduced as the electron beam sweeps across the oscilloscope screen.
- A control that varies the level of illumination for a measuring grid usually incorporated in the transparent faceplate covering the oscilloscope screen.
- Timing controls, which usually consist of sweep-delay and sweep-rate controls, to provide coarse and fine adjustments to suit the material and thickness of the test piece. The sweep-delay control is also used to position the sound entry point on the left side of the display screen, with a back reflection or multiples of back reflections visible on the right side of the screen.
- On/off switch

PIEZOELECTRIC ELEMENT

Transducer Elements

The generation and detection of ultrasonic waves for inspection are accomplished by means of a transducer element acting through a couplet. The transducer element is contained within a device most often referred to as a search unit (or sometimes as a probe). Piezoelectric elements are the most commonly used transducer in ultrasonic inspection, although EMA transducers and magnetostriction transducers are also used.

Piezoelectric Transducers

Piezoelectricity is pressure-induced electricity, this property is characteristic of certain naturally occurring crystalline compounds and some man-made materials. As the name piezoelectric implies, an electrical charge is developed by the crystal when pressure is applied to it. Conversely, when an electrical field is applied, the crystal mechanically deforms (changes shape). Piezoelectric crystals exhibit various deformation modes; thickness expansion is the principal mode used in transducers for ultrasonic inspection. The most common types of piezoelectric materials used for ultrasonic search units are quartz, lithium sulphate, and polarized ceramics such as barium titanate, lead zirconated titanate, and lead meta niobate.

Quartz Crystals

These were initially the only piezoelectric elements used in commercial ultrasonic transducers. Properties of the transducers depended largely on the direction along which the crystals were cut to make the active transducer elements. Principal advantages of quartz-crystal transducer elements are electrical and thermal stability, insolubility in most liquids, high mechanical strength, wear resistance, excellent uniformity, and resistance to aging. A limitation of quartz is its comparatively low electromechanical conversion efficiency, which results in low loop gain for the system.

Lithium Sulphate

The principal advantages of lithium sulphate transducer elements are ease of obtaining optimum acoustic damping for best resolution, optimum receiving characteristics, intermediate conversion efficiency, and negligible mode interaction. The main disadvantages of lithium sulphate elements are fragility and a maximum service temperature of about 75 °C (165 °F).

Polarized Ceramics

Generally, have high electromechanical conversion efficiency, which results in high loop gain and good search-unit sensitivity. Lead zirconated titanate is mechanically rugged, has a good tolerance to moderately elevated temperature, and does not lose polarization with age. It does have a high piezoelectric response in the radial mode, which sometimes limits its usefulness.

Barium titanate is also mechanically rugged and has a high radial-mode response. However, its efficiency changes with temperature, and it tends to depolarize with age. which makes barium titanate less suitable for some applications than lead zirconated titanate. Lead meta niobate exhibits low mechanical damping and good tolerance to temperature. Its principal limitation is a high dielectric constant, which results in a transducer element with a high electrical capacitance.

Selection of a piezoelectric transducer for a given application is done on the basis of size (active area) of the piezoelectric element, characteristic frequency, frequency bandwidth, and type (construction) of search unit. Descriptions of various types of search units with piezoelectric elements are given in the section "Search Units" in this article. Different piezoelectric materials exhibit different electrical-impedance characteristics. In many cases, tuning coils or impedance-matching transformers are installed in the search- unit housing to render a better impedance match to certain types of electronic instrumentation. It is important to match impedances when selecting a search unit for a particular instrument.

Both the amount of sound energy transmitted into the material being inspected (radiated power) and beam divergence are directly related to the size (active area) of the transducer element.

Thus, it is sometimes advisable to use a larger search unit to obtain greater depth of penetration or greater sound beam area.

Each transducer has a characteristic resonant frequency at which ultrasonic waves are most effectively generated and received. This resonant frequency is determined mainly by the material and thickness of the active element. Any transducer responds efficiently at frequencies in a band cantered on the resonant frequency.

The extent of this band, known as bandwidth, is determined chiefly by the damping characteristics of the backing material that is in contact with the rear face of the piezoelectric element.

Straight-beam contact-type units

Manufacturing-induced flaws: -

Billets: inclusions, stringers, pipe

Forgings: inclusions, cracks, segregations, seams, flakes,

Pipe Rolled Products: laminations, inclusions, tears, seams, racks

Castings: slag, porosity, cold shuts, tears, shrinkage cracks, inclusions

Service-induced flaws: -

Fatigue cracks, corrosion, erosion, stress-corrosion cracks

Angle-beam contact-type units

Manufacturing - Induced flaws: -

Forgings: cracks, seams, laps

Rolled products: tears, seams, cracks, cupping

Welds: slag inclusions, porosity, incomplete fusion, incomplete penetration, drop through, suck back, cracks in filler metal and base metal Tubing and pipe: circumferential and longitudinal cracks

Service-induced flaws: -

Fatigue cracks, stress-corrosion cracks

Dual-element contact-type units

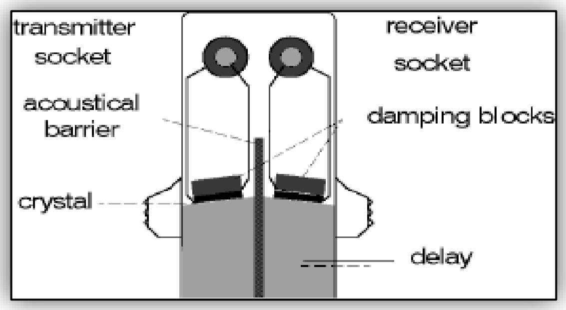
Manufacturing-induced flaws: -

Plate and sheet: thickness measurements, lamination detection

Tubing and pipe:

Service-induced flaws: -

Wall thinning, corrosion, erosion, stress-corrosion cracks



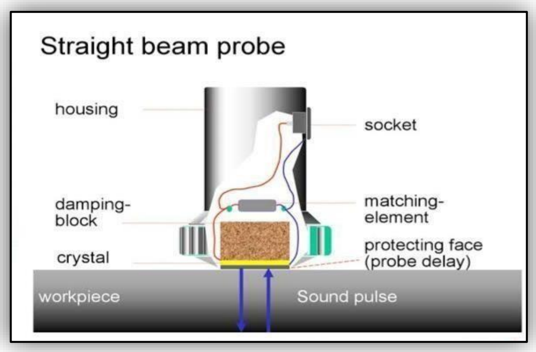


Fig 11: Nomenclature of Angular Probe

Fig 12: Nomenclature of Straight Probe

Contact-Type Units

Although contact-type search units can sometimes be adapted to automatic scanning. they areusually hand held and manually scanned in direct contact with the surface of a test piece. A thin layer of an appropriate couplet is almost always required for obtaining transmission of sound energy across the interface between the search unit and the entry surface.

ANGLE BEAM PROBE (SHEARWAVE)

Angle-Beam Units

The construction of an angle-beam contact-type search unit. A plastic wedge between the piezoelectric element and the contact surface establishes a fixed angle of incidence for the search unit. The plastic wedge must be designed to reduce or eliminate internal reflections within the wedge that could result in undesired false echoes.

Angle-beam search units are used for the inspection of sheet or plate, pipe welds or tubing, and test pieces having shapes that prevent access for straight beam. Angle-beam search units can be used to produce shear waves or combined shear and longitudinal waves, depending on the wedge angle and test piece material.

There is a single value of wedge angle that will produce the desired beam direction and wave type in any given test piece. A search unit having the appropriate wedge angle is selected for each specific application.

The surface wave search unit is an angle-beam unit insofar as it uses a wedge to position the crystal at an angle to the surface of the test piece. It generates surface waves by mode conversion as described in the section "Critical Angles" in This article. The wedge angle is chosen so that the shear wave refraction angle is 90" and the wave resulting from mode conversion travels along the surface.

COUPLANTS

Air is a poor transmitter of sound waves at megahertz frequencies, and the impedance mismatch 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 with piezoelectric transducers, it is necessary to eliminate air between the transducer and the test piece by the use of a couplet.

Couplet normally used for contact inspection include water, oils, glycerine, petroleum greases, silicone grease, wallpaper paste, and various commercial paste like substances. Certain soft rubbers that transmit sound waves may be used where adequate coupling can be achieved by applying hand pressure to the search unit.

The following should be considered in selecting a couplet:

- Surface finish of test piece.
- Temperature of test surface Possibility of chemical reactions between test surface and couplet.
- Cleaning requirements (some couplets are difficult to remove)

Water is a suitable couplet for use on a relatively smooth surface; however, a wetting agent should be added. It is sometimes appropriate to add glycerine to increase viscosity. however, glycerine tends to induce corrosion in aluminium and therefore is not recommended in aerospace applications.

Heavy oil or grease should be used on hot or vertical surfaces or on rough surfaces where irregularities need to be filled.

Heavy oil, grease, or wallpaper paste may not be good choices when water will suffice, because these substances are more difficult to remove. Wallpaper paste, like some proprietary couplet, will harden and may flake off if allowed to stand exposed to air When dry and hard, wallpaper paste can be easily removed by blasting or wire brushing Oil or grease often must be removed with solvents.

Couplet used in contact inspection should be applied as a uniform, thin coating to obtain uniform and consistent inspection results. The necessity for a couplet is one of the drawbacks of ultrasonic inspection and may be a limitation, such as with high-temperature surfaces. When the size and shape of the part being inspected permit, immersion inspection is often done. This practice satisfies the requirement for uniform coupling.

ADVANTAGES AND DISADVANTAGES

The principle advantages of ultrasonic inspection as compared to other methods for non-destructive inspection of metal parts are:

- Superior penetrating power, which allows the detection of flaws deep in the part. Ultrasonic inspection is done routinely to thicknesses of a few meters on many types of parts and to thicknesses of about 6 m (20 ft.) in the axial inspection of parts such as long steel shafts or rotor forgings.
- High sensitivity, permitting the detection of extremely small flaws.
- Greater accuracy than other non-destructive methods in determining the position of internal flaws, estimating their size, and characterizing their orientation, shape, and nature.
- Only one surface needs to be accessible.
- Operation is electronic, which provides almost instantaneous indications of flaws. This makes the method suitable for immediate interpretation, automation, rapid scanning, in-line production monitoring, and process control. With most systems, a permanent t record of inspection results can be made for future reference.
- Volumetric scanning ability, enabling the inspection of a volume of metal extending from front surface to back surface of apart.
- Non-hazardous to operations or to nearby personnel and has no effect on equipment and materials in the vicinity.

- Provides an output that can be processed digitally by a computer to characterize defects and to determine material properties.

The disadvantages of ultrasonic inspection include the following:

- Manual operation requires careful attention by experienced technicians.
- Extensive technical knowledge is required for the development of inspection procedures.
- Parts that are rough, irregular in shape, very small or thin, or not homogeneous are difficult to inspect.
- Discontinuities that are present in a shallow layer immediately beneath the surface may not be detectable.

Applicability

The ultrasonic inspection of metals is principally conducted for the detection of discontinuities. This method can be used to detect internal flaws in most engineering metals and alloys. Bonds produced by welding, brazing, soldering, and adhesive bonding can also be ultrasonically inspected. In-line techniques have been developed for monitoring and classifying material as acceptable, salvageable, or scrap and for process control. Both line-powered and battery-operated commercial equipment is available, permitting inspection in shop, laboratory, warehouse, or field.

Ultrasonic inspection is used for quality control and materials inspection in all major industries. This includes electrical and electronic component manufacturing; production of metallic and composite materials; and fabrication of structures such as airframes, piping and pressure vessels, ships, bridges, motor vehicles, machinery, and jet engines. In-service ultrasonic inspection for preventive maintenance is used for detecting the impending failure of railroad-rolling-stock axles, press columns, earthmoving equipment, mill rolls, mining equipment, nuclear systems, and other machines and components.

Some of the major types of equipment that are ultrasonically inspected for the presence of flaws are:

- Mill components: Rolls, shafts, drives, and press columns.
- Power equipment: Turbine forgings, generator rotors, pressure piping, weldments, pressure vessels, nuclear fuel elements, and other reactor components.
- Jet engine parts: Turbine and compressor forgings, and gear blanks.
- Aircraft components: Forging stock, frame sections, and honeycomb sandwich assemblies.
- Machinery materials: Die blocks, tool steels, and drill pipe.
- Railroad parts: Axles, wheels, track, and welded rail.
- Automotive parts: Forgings, ductile castings, and brazed and/or welded components.

CHAPTER 2

LITERATURE REVIEW

In different Non-destructive methods we have selected ultrasonic testing due to wide range of usage in many applications

Non-destructive techniques are useful for evaluating the condition of structure, by performing indirect assessment of concrete properties. These techniques have been improved in last few years and the best part is that NDT avoids concrete damage for evaluation. Several researchers perform NDT tests to evaluate the condition of concrete structures. Methods range from very simple to technical depending on the purpose.

Several mechanical and physical properties of concrete structures can be used to assess the condition and capacity of the structures. Sanyasi et al. (2012) performed static truck load test on a newly constructed bridge, to capture the response of bridge when a truck travelled across it. Amini and Tehrani (2011) designed experimentally four sets of exposure conditions, weight and compressive strength of the samples had been measured before and after the freeze thaw cycles, and the results were analysed. Loizos and Papavasiliou (2006 performed a comprehensive monitoring and data analysis research study by using Falling Weight deflect meter (FWD) for in situ evaluation of recycled pavements, Prover bio and Venturi (2005) evaluated the reliability of rebound hammer test and UPV test on concrete of different composition and strength. Rens et al. (2005) explained application of NDE methods for bridge inspection, which is Bridge Evaluation Using NDT (BENT). Malabar et al. (2003) used pull off tests to evaluate effects of temperature, moisture, and chloride content on CFRP adhesion. Pascal et al. (2003) carried out an experimental program involving both destructive and non-destructive methods applied to different concrete mixtures, with cube strength varying from 30 to 150 MPa, to define a relation between strength and parameters. Tests performed are pulse velocity, rebound hammer, pull out, and probe penetration, micro coring and combined methods. Almir and Portacio (2000) ssused NDT methods to determine the compressive strength of concrete relationship between the measured mechanical or physical properties and the strength and also presented the validity of pull off, pin penetration, and UPV for assessing the concrete strength. Chen et al. (1995) presented findings of research on fibre optic Bragg gratings as stress/strain sensors for monitoring the critical sections of composite beams.

CHAPTER 3

GENERATION OF ULTRASONIC WAVES

Ultrasonic waves are mechanical waves (in contrast to, for example, light or x-rays which are electromagnetic waves) that consist of oscillations or vibrations of the atomic of molecular particles of a substance about the equilibrium positions of these particles Ultrasonic waves behave essentially the same as audible sound waves. They can propagate in an elastic medium, which can be solid, liquid, or gaseous, but not in a vacuum.

In many respects, a beam of ultrasound is similar to a beam of light, both are waves and obey a general wave equation. Each travel at a characteristic velocity in a given homogeneous medium-a velocity that depends on the properties of the medium, not on the properties of the wave. Like beams of light, ultrasonic beams are reflected from surfaces, refracted when they cross a boundary between two substances that have different characteristic sound velocities, and diffracted at edges or around obstacles. Scattering by rough surfaces or particles reduces the energy of an ultrasonic beam, comparable to the manner in which scattering reduces the intensity of a light beam.

Analogy with Waves in Water

The general characteristics of sonic or ultrasonic waves are conveniently illustrated by analogy with the behaviour of waves produced in a body of water when a stone is dropped into it. Casual observation might lead to the erroneous conclusion that the resulting outward radial travel of alternate crests and troughs represents the movement of water away from the point of impact. The fact that water is not thus transported is readily deduced from the observation that a small object floating on the water does not move away from the point of impact, but instead merely bobs up and down. The waves travel outward only in the sense that the crests and troughs (which can be compared to the compressions and rarefactions of sonic waves in an elastic medium) and the energy associated with the waves propagate radially outward. The water particles remain in place and oscillate up and down from their normal positions of rest.

Continuing the analogy, the distance between two successive crests or troughs is the wavelength A. The fall from a crest to a trough and subsequent rise to the next crest (which is accomplished within this distance) is a cycle. The number of cycles in a specific unit of time is the frequency, f, of the waves. The height of a crest or the depth of a trough in relation to the surface at equilibrium is the amplitude of the waves.

The velocity of a wave and the rates at which the amplitude and energy of a wave decrease as it propagates are constants that are characteristic of the medium in which the wave is propagating Stones of equal size and mass striking oil and water with equal force will generate waves that travel at different velocities. Stones impacting a given medium with greater energy will generate waves having greater amplitude and energy but the same wave velocity.

The above attributes apply similarly to sound waves, both audible and ultrasonic. propagating in an elastic medium. The particles of the elastic medium move, but they do not migrate from their initial special orbits, only the energy travels through the medias The amplitude and energy of sound waves in the elastic medium depend on the amount of energy supplied. The velocity and attenuation (loss of amplitude and energy) of the sound waves depend on the properties of the medium in which they are propagating.

Wave Propagation

Ultrasonic waves (and other sound waves) propagate to some extent in any elastic material. When the atomic or molecular particles of an elastic material are displaced from their equilibrium positions by any applied force, internal stress acts to restore the particles to their original positions. Because of the interatomic forces between adjacent particles of material, a displacement at one point induces displacements at neighbouring points and so on, thus propagating a stress-strain wave. The actual displacement of matter that occurs in ultrasonic waves is extremely small. The amplitude, vibration mode, and velocity of the waves differ in solids, liquids, and gases because of the large differences in the distance between particles in these forms of matter. These differences influence the forces of attraction between particles and the elastic behaviour of the materials.

The concepts of wavelength, cycle, frequency, amplitude, velocity, and attenuation described in the preceding section "Analogy with Waves in Water" in this article apply in general to ultrasonic waves and other sound waves. The relation of velocity to frequency and wavelength is given by:

V= f(lambda)

Where V is velocity (in meters per second), is frequency (in hertz), and alpha is wavelength (in meters per cycle). Other consistent units of measure can be used for the variables in g 1, were convenient.

On the basis of the mode of particle displacement, ultrasonic waves are classified as longitudinal waves, transverse waves, surface waves, and Lamb waves. These four types of waves are described in the following sections.

TYPES OF ULTRASONIC WAVES

LONGITUDINAL WAVE

Sometimes called compression waves, are the type of ultrasonic waves most widely used in the inspection of materials. These waves travel through materials as a series of alternate compressions and rarefactions in which the particles transmitting the wave vibrate back and forth in the direction of travel of the waves.

Longitudinal ultrasonic waves and the corresponding particle oscillation and resultant rarefaction and compression are shown schematically in Fig. 1(a), a plot of amplitude of particle displacement versus distance of wave travel, together with the resultant rarefaction trough and compression crest, is shown in Fig. 10. The distance from one crest to the next (which equals the distance for one complete cycle of rarefaction and compression) is the wavelength, lambda. The vertical axis in Fig. 10, could represent pressure instead of particle displacement. The horizontal axis could represent time instead of travel distance because the speed of sound is constant in a given material and

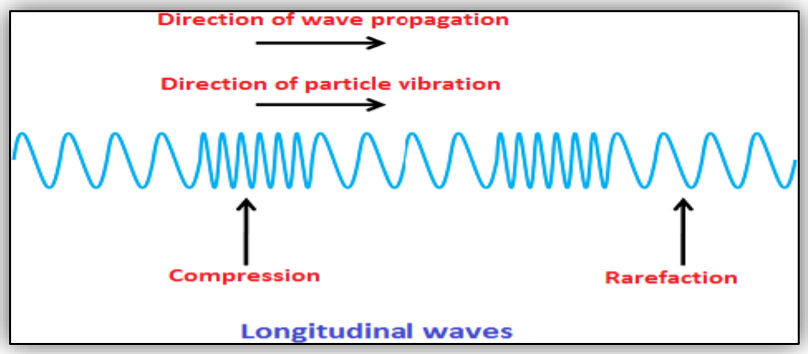


Fig 13: Longitudinal Wave Propagation

Longitudinal ultrasonic waves are readily propagated in liquids and gases as well as in elastic solids. The mean free paths of the molecules of liquids and gases at a pressure of 1 at m are so short that longitudinal waves can be propagated simply by the elastic collision of one molecule with the next. The velocity of longitudinal ultrasonic waves is about 6000 m/s (20,000 ft./s) in steel, 1500 m/s (5000 ft/s) in water, and 330 m/s (1080 ft/s) in air.

TRANSVERSE WAVES (SHEAR WAVES)

These are also extensively used in the ultrasonic inspection of materials. Transverse waves are visualized readily in terms of vibrations of a rope that is shaken rhythmically, in which each particle, rather than vibrating parallel to the direction of wave motion as in the longitudinal wave, vibrates up and down in a plane perpendicular to the direction of propagation. A transverse wave is illustrated schematically in Fig. 2, which shows particle oscillation, wave front, direction of wave travel, and the wavelength, lambda, corresponding to one cycle.

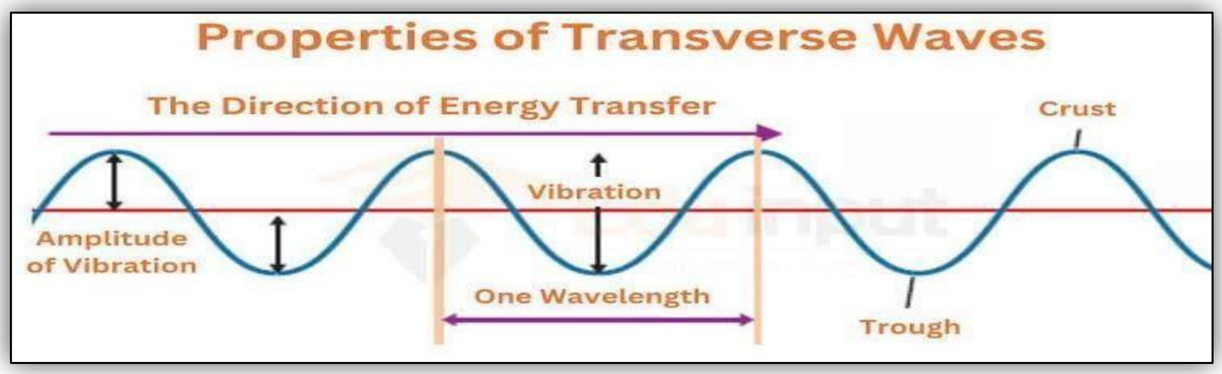


Fig 14: Transverse Wave Propagation

Unlike longitudinal waves, transverse waves cannot be supported by the elastic collision of adjacent molecular or atomic particles. For the propagation of transverse waves, it is necessary that each particle exhibit a strong force of attraction to its neighbours so that as a particle moves back and forth it pulls its neighbour with it, thus causing the sound to move through the material with the velocity associated with transverse waves, which is about 50% of the longitudinal wave velocity for the same material.

Air and water will not support transverse waves. In gases, the forces of attraction between molecules are so small that shear waves cannot be transmitted. The same is true of a liquid, unless it is particularly viscous or is present as a very thin layer.

ANGLE OF INCIDENCE

Only when an ultrasonic wave is incident at right angles on an interface between two materials (normal incidence; that is, angle of incidence - 0") do transmission and reflection occur at the interface without any change in beam direction. At any other angle of incidence, the phenomena of mode conversion (a change in the nature of the wave motion) and refraction (a change in direction of wave propagation) must be considered.

These phenomena may affect the entire beam or only a portion of the beam and the sum total of the changes that occur at the interface depend on the angle of incidence and the velocity of the ultrasonic waves leaving the point of impingement on the interface.

All possible ultrasonic waves leaving this point are shown for an incident longitudinal ultrasonic wave in Fig. 5. Not all the waves shown in Fig. 5 will be produced in any specific instance of oblique impingement of an ultrasonic wave on the interface between two materials. The waves that propagate in a given instance depend on the ability of a waveform to exist in a given material, the angle of incidence of the initial beam, and the velocities of the waveforms in both materials.

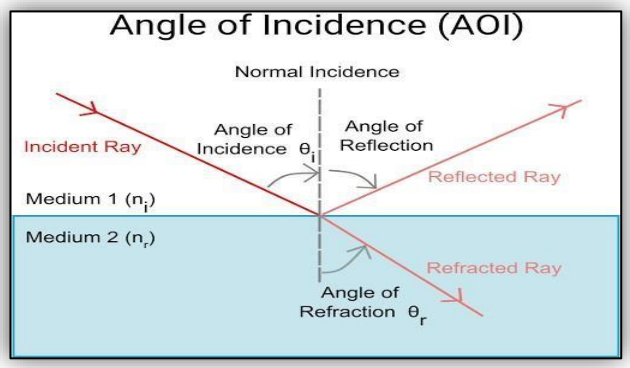


Fig 15: Incidence Angle

The general law that describes wave behaviour at an interface is known as Snell's law, although originally derived for light waves, Snell's law applies to acoustic waves (including ultrasound) and to many other types of waves. According to Snell's law, the ratio of the sine of the angle of incidence to the sine of the angle of reflection or refraction equals the ratio of the corresponding wave velocities. Snell's law applies even if mode conversion takes place.

Mathematically, Snell's law can be expressed as:

sin alpha/ sin beta = V_ {1} / V_ {2}

Where the angle of incidence is alpha, beta is the angle of reflection or refraction, and P, and_ {2} are the respective velocities of the incident and reflected or refracted waves. Both and beta are measured from a line normal to the interface.

Fallowing is the general relationship applying to reflection and refraction, taking into account all possible effects of mode conversion for an incident longitudinal ultrasonic wave, as shown in Fig

where alpha 1 is the angle of incidence for incident longitudinal wave if material 1,, is the angle of reflection for reflected (inguinal wave in material 1-is the angle of reflection for reflected transverse wave in material 1, B, is the angle of refraction for refracted longitudinal wave in material 2, P, is the angle of refraction for refracted transverse wave in material 2.V is the velocity of incident longitudinal wave in material 1 velocity of reflected longitudinal wave in material 1, V) is the velocity of reflected transverse wave in material 1,licy is the velocity of refracted longitudinal wave in material 2, and V (2) is the velocity of refracted transverse wave in material2.

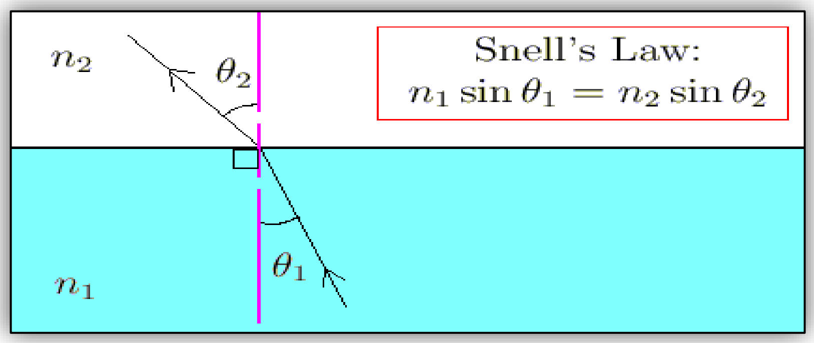


Fig 16: Snell's Law

CRITICAL ANGLES

If the angle of incidence is mall, sound waves propagating in a given medium May undergo mode conversion at a boundary, resulting in the simultaneous propagation of longitudinal and transverse (shear) waves in a second medium. If the angle is increased, the direction of the refracted longitudinal wave will approach the plane of the boundary (8, 90°). At some specific value of1, B, will exactly equal 90°, above which the refracted long turdine wave will no longer propagate in the material, leaving only a refracted (mode-converted) shear w wave to propagate in the second medium. This value of is known as the first critical angle. If, is increased beyond the first critical angle, the direction of the refracted shear wave will approach the plane of the boundary (P, 90"). At a second specific value of will exactly equal 90°, above which the refracted transverse wave will no longer propagate in the material. This second value of is called the second critical angle.

Critical angles are of special importance in ultrasonic inspection. Values of I between the first and second critical angles are required for most angle- beam inspections Surface wave inspection is accomplished by adjusting the incident angle of a contact-type search unit so that it is a few tenths of a degree greater than the second critical angle. At this value, the refracted shear wave in the bulk material is replaced by a Rayleigh wave traveling along the surface of the test piece. As mentioned earlier in this article, Rayleigh waves can be effectively sustained only when the medium on one side of the interface (in this case, the surface of the test piece) is a gas Consequently, surface wave inspection is primarily used with contact methods.

Frequently, it is desirable to produce shear waves in a material at an angle of 45" to the surface. In most materials, incident angles for mode conversion to a 45° shear wave lie between the first and second critical angles. Typical values of 1 for all three of these--first critical angle, second critical angle, and incident angle for mode conversion to 45 shears.

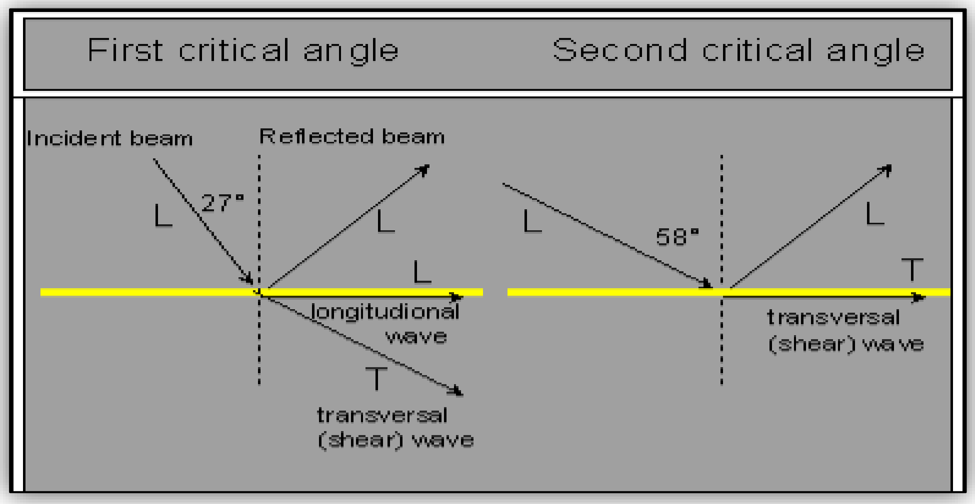


Fig 17: Critical Angles

(a) Measured from a direction normal to surface of test material.

(b) In water at 4 °C (39 °F).

(c) Using angle block (wedge) made of a crystal plastic.

Beam Intensity

The intensity of an ultrasonic beam is related to the amplitude of particle vibrations Acoustic pressure (sound pressure) is the term most often used to denote the amplitude of alternating stresses exerted on a material by a propagating ultrasonic wave.

Acoustic pressure is directly proportional to the product of acoustic impedance and amplitude of particle motion.

The acoustic pressure exerted by a given particle varies in the same direction and with the same frequency as the position of that particle changes with time. Acoustic pressure is the most important property of an ultrasonic wave, and its square determines the amount of energy (acoustic power) in the wave. It should be noted that acoustic pressure is not the intensity of the ultrasonic beam. Intensity, which is the energy transmitted through a unit cross-sectional area of the beam, is proportional to the square of acoustic pressure.

Although transducer elements sense acoustic pressure, ultrasonic systems do not measure acoustic pressure directly. However, receiver-amplifier circuits of most ultrasonic instruments are designed to produce an output voltage proportional to the square of the input voltage from the transducer. Therefore, the signal amplitude of sound that is displayed on an oscilloscope or other readout device is a value proportional to the true intensity of the reflected sound.

Acoustic Impedance Effects

These (see the section "Acoustic Impedance" in this article) can be used to calculate the amount of sound that reflects during the ultrasonic inspection of a test piece immersed in water. For example, when an ultrasonic wave impinges at normal incidence (1-0) to the surface of the flaw-free section of aluminium alloy 1100 plate during straight-beam inspection, the amount of sound that returns to the search unit (known as the back reflection) has only 6% of its original intensity. This reduction in intensity occurs because of energy partition when waves are only partly reflected at the aluminium/water interfaces. (Additional losses would occur because of absorption and scattering of the ultrasonic waves, as discussed in the sections "Absorption" and "Scattering" in this article.)

Similarly, an energy loss can be calculated for a discontinuity that constitutes an ideal reflecting surface, such as a lamination that is normal to the beam path and that interposes a metal/ air interface larger than the sound beam. For example, in the straight- beam inspection of an aluminium alloy 1100 plate containing a lamination, the final returning beam, after partial reflection at the front surface of the plate and total reflection from the lamination, would have a maximum intensity 8% of that of the incident beam.

The loss in intensity of returning ultrasonic beams is one basis for characterizing News in metal test pieces. As indicated above, acoustic impedance losses can severely diminish the intensity of an ultrasonic beam. Because a small fraction of the area of a sound beam is reflected from small discontinuities, it is obvious that ultrasonic students must be extremely sensitive to small variations in intensity if small discontinuities are to be detected. The sound intensity of contact techniques is usually greater than that of immersion techniques; that is, smaller discontinuities will result in higher amplitude signals. Two factors are mainly responsible for this difference, as follows.

First, the back surface of the test piece is a metal/air interface, which can be commandeered a total reflector. Compared to a metal/water interface, this results in an approximately 30% increase in back reflection intensity at the receiving search unit for an aluminium test piece coupled to the search unit through a layer of water.

Second, if a couplet whose acoustic impedance more nearly matches that of the test piece is substituted for the water, more energy is transmitted across the interface for both the incident and returning beams. For most applications, any couplet with acoustic impedance higher than that of water is preferred. Several of these are listed in the nonmetals group in Table 1. In addition to the liquid couplet listed in Table 1, several semisolid or solid couplet (including wallpaper paste, certain greases, and some adhesives) have higher acoustic impedances than water.

NEAR-FIELD AND FAR-FIELD EFFECTS

The face of an ultrasonic-transducer crystal does not vibrate uniformly under the influence of an impressed electrical voltage. Rather, the crystal face vibrates in a complex manner that can be most easily described as a mosaic of tiny, individual crystals, each vibrating in the same direction but slightly out of phase with its neighbours. Each element in the mosaic acts like a point (Huygens) source and radiates a spherical wave outward from the plane of the crystal face. Near the face of the crystal, the composite sound beam propagates chiefly as a plane wave, although spherical waves emanating from the periphery of the crystal face produce short-range ultrasonic beams referred to as side lobes.

Along the central axis of the composite sound beam, the series of acoustic pressure maximums and minimums becomes broader and more widely spaced as the distance from the crystal face, d, increases. Where d becomes equal to N (with N denoting the length of near field), the acoustic pressure reaches a final maximum and decreases proximately exponentially with increasing distance, as shown in Fig. 8. The length of the near field is determined by the size of the radiating crystal and the wave-length, lambda of the ultrasonic wave. For a circular radiator of diameter D, the length of near field can be calculated from:

N = (D ^ 2 - lambda ^ 2)/(4lambda)

when the wavelength be approximated by: respect to the crystal diameter, the near-field length can.

N = (D ^ 2)/(4lambda) = A/(pi*lambda)

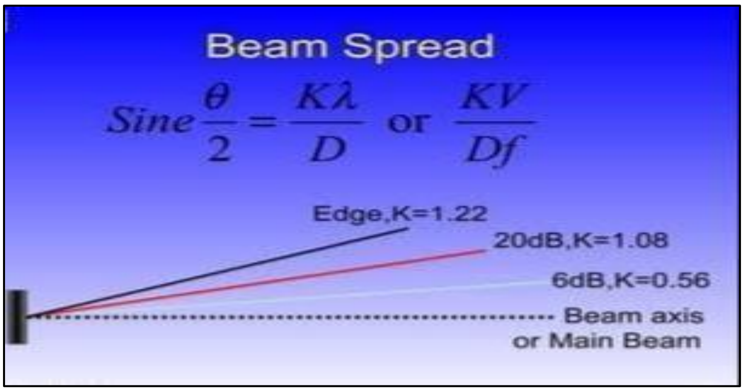


Fig 18: Beam Spread

At distances greater than N, known as the far field of the ultrasonic beam, there are interference effects. At distances from N to about 3N from the face of a circular radiator, there is a gradual transition to a spherical wave front. At distances of more than about 3N, be ultrasonic beam from a rectangular radiator more closely resembles a cylindrical wave, with the wave front being curved about an axis parallel to the long dimension of the rectangle.

CHAPTER 4

BASIC INSPECTION METHOD

This method is used to inspect and check weather flaw detector accuracy when calibrated with standard block.

The two major methods of ultrasonic inspection are the transmission method and the pulse-echo method. The primary difference between these two methods is that the transmission method involves only the measurement of signal attenuation, while the pulse- echo method can be used to measure both transit time and signal attenuation.

The pulse-echo method, which is the most widely used ultrasonic method, involves the detection of echoes produced when an ultrasonic pulse is reflected from a discontinuity or an interface of a test piece. This method is used in flaw location and thickness measurements. Flaw depth is determined from the time-of-flight between the initial pulse and the echo produced by a flaw. Flaw depth might also be determined by the relative transit time between the echo produced by a flaw and the echo from the back surface. Flaw sizes are estimated by comparing the signal amplitudes of reflected sound from an interface (either within the test piece or at the back surface) with the amplitude of sound reflected from a reference reflector of known size or from the back surface of a test piece having no flaws.

The transmission method, which may include either reflection or through transmission, involves only the measurement of signal attenuation. This method is also used in flaw detection. In the pulse-echo method, it is necessary that an internal flaw reflect at least part of the sound energy onto a receiving transducer. However, echoes from flaws are not essential to their detection. Merely the fact that the amplitude of the back reflection from a test piece is lower than that from an identical work piece known to be free of flaws implies that the test piece contains one or more flaws. The technique of detecting the presence of flaws by sound attenuation is used in transmission methods as well as in the pulse-echo method. The main disadvantage of attenuation methods is that flaw depth cannot be measured.

The principles of each of these two inspection methods are discussed in the following sections, along with corresponding forms of data presentation, interpretation of data, and effects of operating variables.

Subsequent sections describe various components and systems for ultrasonic inspection, reference standards, and inspection procedures and applications.

In addition, the article "Boilers and Pressure Vessels" in this Volume contains information on advanced ultrasonic techniques.

The application of ultrasonic techniques also involves other methods, such as acoustical holography, acoustical microscopy, the frequency modulation technique, spectral analysis, and sound conduction. The first two of these methods are discussed in the articles "Acoustical Holography" and "Acoustic Microscopy" in this Volume. The other three methods are briefly summarized below.

The frequency modulation (FM) method

which was the precursor of the pulse-echo method, is another flaw detection technique. In the FM method, the ultrasonic pulses are transmitted in wave packets whose frequency varies linearly with time. The frequency variation is repeated in successive wave packets so that a plot of frequency versus time has a saw tooth pattern. Returning echoes are displayed on the readout device only if they have certain characteristics as determined by the electronic circuitry in the instrument. Although not as widely used as the pulse-echo method, the FM method has a lower signal-to-noise ratio and therefore somewhat greater resolving power.

Spectral analysis

which can be used in the through transmission or pulse-echo methods, involves determination of the frequency spectrum of an ultrasonic wave after it has propagated through a test piece. The frequency spectrum can be determined either by transmitting a pulse and using a fast Fourier transform to obtain the frequency spectrum of the received signal or by sweeping the transmission frequency in real time and acquiring the response at each frequency. The increasing use of the pulse method is attributed to improvements in the speed of digital fast Fourier transform devices.

Spectral analysis is used in transducer evaluations and may be useful in defect characterization. However, because the spectral signatures of defects are influenced by several other factors (such as the spectrum of the input pulse, coupling details, and signal attenuation), defect characterization primarily involves the qualitative interpretation of echoes in the time domain (see the section "Interpretation of Pulse-Echo Data" in this article.

Spectral analysis can also be used to measure the thickness of thin-wall specimens. Ashort pulse of ultrasound is a form of coherent radiation; in a thin-wall specimen that produces front and back wall echoes, the two reflected pulses show phase differences and can interfere coherently. If the pulse contains a wide band of frequencies, interference maxima and minima can occur at particular frequencies, and these can be related to the specimen thickness.

Pulse-Echo Methods

In pulse-echo inspection, short bursts of ultrasonic energy (pulses) are introduced into a test piece at regular intervals of time. If the pulses encounter a reflecting surface, some or all of the energy is reflected. The proportion of energy that is reflected is highly dependent on the size of the reflecting surface in relation to the size of the incident ultrasonic beam. The direction of the reflected beam (echo) depends on the orientation of the reflecting surface with respect to the incident beam. Reflected energy is monitored; both the amount of energy reflected in a specific direction and the time delay between transmission of the initial pulse and receipt of the echo are measured.

Principles of Pulse-Echo Methods

Most pulse-echo systems consist of

- An electronic clock.
- An electronic signal generator, or pulser
- A sending transducer
- A receiving transducer
- An echo-signal amplifier.
- A display device

In the most widely used version of pulse-echo systems, a single transducer acts alternately as a sending and receiving transducer. The clock and signal generator are usually combined in a single electronic unit. Frequently, circuits that amplify and demodulate echo signals from the transducer are housed in the same unit. Specific characteristics of transducers and other equipment are discussed in subsequent sections of this article.

The clock activates a time-measuring circuit connected to the display device. The operator can preselect a constant interval between pulses by means of a pulse-repetition rate control on the instrument; pulses are usually repeated 60 to 2000 times per second.

In most commercially available flaw detectors, the pulse-repetition rate is controlled automatically except for some larger systems. Also, most systems are broadband when they transmit, but may be tuned or filtered for reception. The operator can also preselect the output frequency of the signal generator. For best results, the frequency should be tuned to achieve the maximum response of the transducer and maximum signal-to-noise ratio (lowest amount of electronic noise) in the electronic equipment.

The transducer then converts the pulse of voltage into a pulse of mechanical vibration having essentially the same frequency as the imposed alternating voltage. The mechanical vibration (ultrasound) is introduced into a test piece through a couplet and travels by wave motion through the test piece at the velocity of sound, which depends on the material. When the pulse of ultrasound encounters a reflecting surface that is perpendicular to the direction of travel, ultrasonic energy is reflected and returns to the transducer. The returning pulse travels along the same path and at the same speed as the transmitted pulse, but in the opposite direction. Upon reaching the transducer through the couplet, the returning pulse causes the transducer element to vibrate, which induces an alternating electrical voltage across the transducer.

Theoretically, the maximum depth of inspection is controlled by the pulse-repetition rate. For example, if a 10 MHz pulse is transmitted at a pulse-repetition rate of 500 pulses per second, a longitudinal wave pulse can travel almost 12 m (40 ft) in steel or aluminium before the next pulse is triggered. This means one pulse can travel to a depth of 6 m (20) and return before the next pulse is initiated.

Practically, however, inspection can be performed only to a depth that is considerably less than the theoretical maximum. Sound attenuation in a test piece can limit the path length. The practical limit varies with the type and condition of the test material. test frequency, and system sensitivity. Furthermore, it is highly desirable for all ultrasonic vibrations (including successively re-reflected echoes of the first reflected pulse) to die out in the test piece before the next initial pulse is introduced. As a rule, the pulse-repetition rate should be set so that one pulse can traverse the test piece enough times to dissipate the sonic energy to a non-displayable level before the next pulse is triggered.

Flaw location (depth) is determined from the position of the flaw echo on the oscilloscope screen. With a calibrated time, base (the horizontal sweep of the oscilloscope), flaw location can be measured from the position of its echo on the horizontal scale calibrated to represent sound travel within the test object. The zero point on this scale represents the entry surface of the test piece.

4.5 BASIC A-SCAN DISPLAYS

A-scan displays are of the type shown in fallowing Fig for the immersion inspection of a plate containing a flaw. The test material was 25 mm (1 in) thick aluminium alloy 1100 plate containing a purely reflecting planar flaw. The flow depth was 45% of plate thickness (11.25 mm, or 0.44 in.), exactly parallel to the plate surfaces, and had an area equal to one-third the cross section of the sound beams. Straight-beam immersion testing was done in a water-filled tank.

There were negligible attenuation losses within the test plate, only transmission losses across front and back surfaces of the complete display. The normal display is obtained by adjusting two of the oscilloscope controls to display only the portion of the trace corresponding to the transit time required for a single pulse of ultrasound to traverse the test piece from front surface to back surface and return. Also, the gain in the receiver- amplifier is adjusted so that the height of the first back reflection equals some arbitrary vertical distance on the screen, usually a convenient number of gridlines.

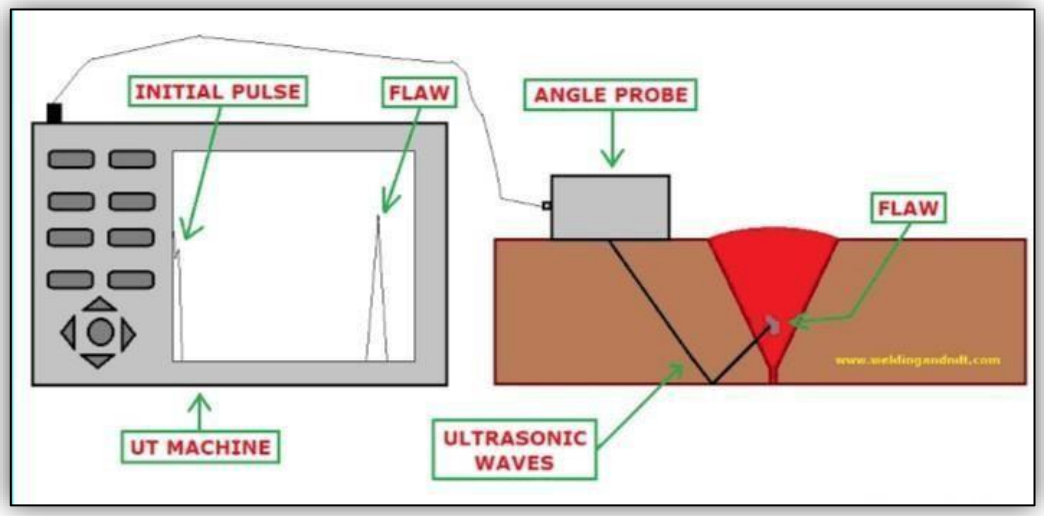


Fig 19: Angle Beam Scanning

As illustrated in Fig, there is a tendency for echoes to reverberate, that is, to bounce back and forth between reflecting surfaces. Each time an echo is reflected from the front surface, a portion of the sound wave energy escapes through the boundary to impinge on the transducer and produce an indication on the display. In Fig. 13(b), the indications labelled 1 through 6 are reverberations of the back reflection, those labelled A through & are reverberations of the primary flaw echo, and those labelled X through Z are reverberations of a subordinate flaw echo induced by re-reflection of the first back reflection.

4.6. ECHO SHAPE

Echo shape is primarily affected by the shape, orientation, and sound-reflecting characteristics of an interface. Metal/air interfaces produce sharp indications if the interfaces are relatively smooth and essentially parallel to the front surface. If an interface is curved (such as the surface of a large pore) or rough (such as a crack, seam, or lamination) or if it is not ideally reflecting (such as the surface of a metallic inclusion or a slag inclusion), the interface will produce a broadened echo indication,

As shown in Fig. 17. If the interface is smaller in area than the cross section of the ultrasonic beam or if ultrasonic waves are transmitted through the interface, a back-surface echo (back reflection) will appear to the right of the flaw echo on the oscilloscope screen, as shown in Fig. 17. However, if the flaw is larger than the ultrasonic beam or if the back surface is not normal to the direction of wave travel, no back reflection will appear on the

rein, as shown in Fig. 17. Often, the amplitude of a broad indication will decrease with increasing depth, as in Fig. 17, especially when the echo is from a crack, seam, or lamination rather than an inclusion. Sometimes, especially if the echo is from a spherical flaw or from an interface that is not at right angles to the sound beam, the echo amplitude will increase with depth.

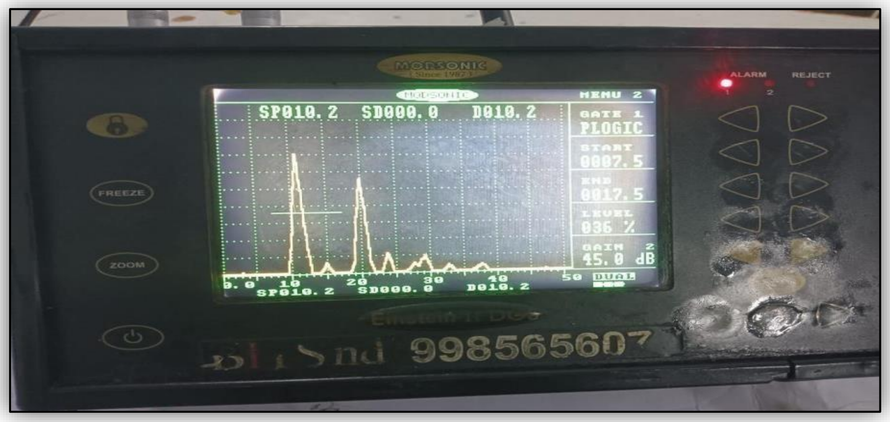


Fig 20: Echo Shape

ECHO AMPLITUDE

which is a measure of the intensity of a reflected sound beam, is a direct function of the area of the reflecting interface for flat parallel reflectors. If the interface is round or curved or is not perpendicular to the sound beam, echo amplitude will be reduced. The effects of roughness, shape, and orientation of the interface on echo amplitude must be understood because these factors introduce errors in estimates of flaw size.

Flaw size is most often estimated by comparing the amplitude of an echo from an interface of unknown size with the amplitude of echoes from flat-bottom holes of different diameter in two or more reference blocks. To compensate for any sound attenuation within the test piece, these guidelines should be followed:

• Reference holes should be about the same depth from the front (entry) surface of the reference block as the flaw is from the front surface of the test piece

• Reference blocks should be made of material with acoustic properties similar to those of the test piece.

The sound beam should be larger than the flaw. (This can best be determined by moving the search unit back and forth on the surface of the part being inspected relative to a position cantered over the flaw and observing the effect on both flaw echo and back reflection. If the search unit can be moved slightly without affecting the height of either the flaw echo or back reflection, it can be assumed that the sound beam is sufficiently larger the flaw

• Control settings on the instrument and physical arrangement of search unit, couplet, and specimen are the same regardless of whether the specimen is a test piece or a reference block

In practice, a calibration curve is constructed using reference blocks, as described in the section "Determination of Area- Amplitude and Distance-Amplitude Curves" in this article. Flaw size is then determined by reading the hole size corresponding to the amplitude of the flaw echo directly from the calibration curve. Flaw size determined in this manner is only an estimate of minimum size and should not be assumed equal to the actual flaw size. The amount of sound energy reflected back to the search unit will be less than that from a flat-bottom hole of equal size if an interface has a surface rougher than the bottom surfaces of the reference holes, is oriented at an angle other than 90° to the sound beam, is curved, or transmits some of the sound energy rather than acting as an ideal reflector.

ADVANTAGES OF NDT:

Non-Destructive Testing (NDT) is a set of techniques used to evaluate the properties of materials, components, or systems without causing any damage to the structure or its functionality. NDT is widely employed in various industries to ensure the quality, safety, and reliability of materials and products.

No Damage to Tested Items:

NDT methods do not cause any damage to the materials or structures being tested, allowing them to remain intact and functional after the inspection.

Cost-Effective:

In many cases, NDT is more cost-effective than destructive testing, as it eliminates the need for replacing or repairing tested items.

Time Efficiency:

NDT techniques are often quicker than traditional destructive methods, leading to reduced downtime in industrial processes.

Quality Assurance:

NDT helps ensure the quality and integrity of materials, components, or structures, contributing to the overall reliability and safety of products.

Repeatability:

NDT methods provide consistent and repeatable results, allowing for reliable monitoring and assessment over time.

Enhanced Safety:

As NDT methods do not involve physical damage to the items being tested, they contribute to a safer working environment.

Wide Range of Applications:

NDT is applicable to various materials, including metals, plastics, ceramics, composites, and more, making it versatile for different industries.

DISADVANTAGES OF NDT:

Limited Sensitivity:

Some NDT methods may have limitations in detecting very small defects, especially in complex structures or with certain materials.

Skilled Personnel Required:

Properly conducting NDT requires trained and skilled personnel to ensure accurate and reliable results.

Equipment Costs:

The initial cost of NDT equipment can be high, and maintenance costs should also be considered.

Surface Accessibility:

Certain NDT methods require direct access to the surface being tested, which can be challenging in certain applications or environments.

Interpretation of Results:

Interpretation of NDT results may require expertise, and false positives or negatives can occur if not properly analyzed.

APPLICATION ON NDT:

Aerospace Industry:

Used to inspect aircraft components like wings, fuselage, and engine parts for defects.

Oil and Gas Industry:

Employed for inspecting pipelines, welds, and storage tanks to ensure structural integrity and prevent leaks.

Power Generation:

NDT is used in the inspection of power plant components, such as turbines, boilers, and pipelines.

Automotive Industry:

Applied to assess the integrity of automotive components, including welds, castings, and composite materials.

Construction:

Used to inspect bridges, buildings, and other structures for defects or deterioration.

Railway Industry:

NDT is employed for inspecting rails, wheels, and other critical components to ensure safe operation.

Manufacturing:

NDT is used in various manufacturing processes to detect flaws in materials and ensure product quality.

Nuclear Industry:

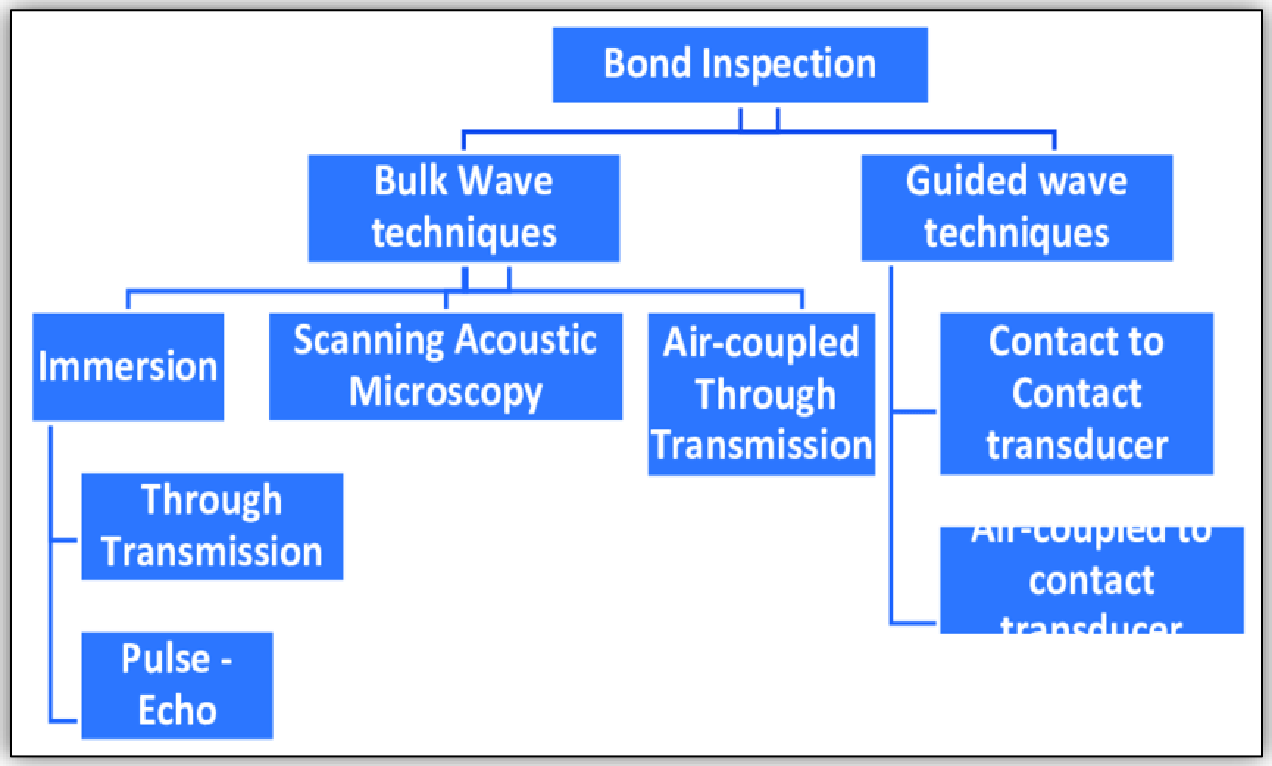
Applied to inspect nuclear power plant components for any defects that could compromise safety.

CHAPTER 5

TESTING METHODS

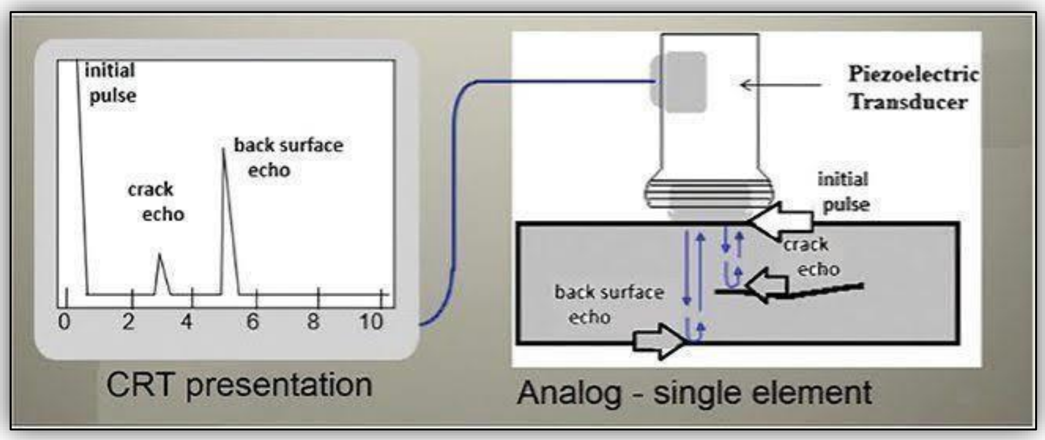
Testing methods are used for testing defects on unknown specimen and deals about echo size and its formation.

Evaluation of discontinuities Of course, a discontinuity is best evaluated when its size (extension) is known. The operator's wish to accurately know the "real reflector size" is understandable therefore it is expected that a non-destructive testing method, such as ultrasonic testing, give this information. However, due to the fact that on the display only the echo can be interpreted, this means the reflected sound coming from the discontinuity, it is very often difficult, and in some cases even impossible, to reliably assert the size of the reflector. In fact, the echo height plays the decisive part when evaluating discontinuities during manual Ultrasonic Testing.



5.1 SCANNING METHODS

In ultrasonic evaluation one is frequently able to come near to the true reflector size as long as the discontinuity is large compared to the diameter of the sound field. The discontinuity then reflects the complete impacting energy back, Fig. By scanning the boundaries of the discontinuity, reliable information can be obtained about its extension. The ultrasonic operator normally observes the height of the discontinuity echo. The probe position on the test object at which the echo drops by exactly half



indicates that the discontinuity is only being hit by half the sound beam, Fig 18.

Fig 22: Sound Reflection

This means that the acoustic axis is exactly on the boundary of the discontinuity. The probe position is marked and the operator determines further boundary points until a contour of the discontinuity is formed by joining the marked points together, Fig. Location of the reflector boundary becomes more exact the smaller the diameter of the sound beam is at the reflector position.

If the reflector extension is to be exactly measured it is recommended that a probe be selected which has its focal point at the same distance as the reflector. TR probes are especially suited which have a hose- shaped sound beam with a small diameter (1-3 mm) at their most sensitive depth range Under optimal conditions, e.g., drill holes with flat bottoms and at equal depths, this law can be confirmed:

Example: The flat-bottom hole with a diameter of 2 mm has an echo which is 4 times that of a 1 mm flat-bottom hole because the area has quadrupled. However, if the echoes from two drill holes at different depths are compared then an additional distance dependence of the echo heights is established, Fig.

With accurate tests using flat-bottom holes at different depths a simple law can be found. at least in the far field of the applied sound beam.

Sound attenuation

In addition to the laws which establish the behaviour of disk-shaped reflectors within the sound beam of a probe (distance and size laws) another effect can be observed: The sound attenuation. The sound attenuation is caused by the structure of the test object but is also strongly dependent on the frequency and the wave mode of the applied probe. Only when these effects are known can they be considered by the discontinuity evaluation.

The reference block method

These uncertainties in evaluation can be reduced when there is a so-called reference block available which is made of the same material as the object to be tested and which also contains artificial reflectors whose echoes can be directly compared to the discontinuity echoes from the test object. The application of the reference block method is, in practice, made in two different ways:

Comparison of echo amplitudes

The test object is tested with a high gain setting by which the smallest detectable reflector is displayed. An echo indication is peaked, i.e., the maximum echo indication is achieved by careful movement of the probe and the echo peak set by adjustment of the gain to a predetermined height, e.g., 80%. CRT screen height (reference height).

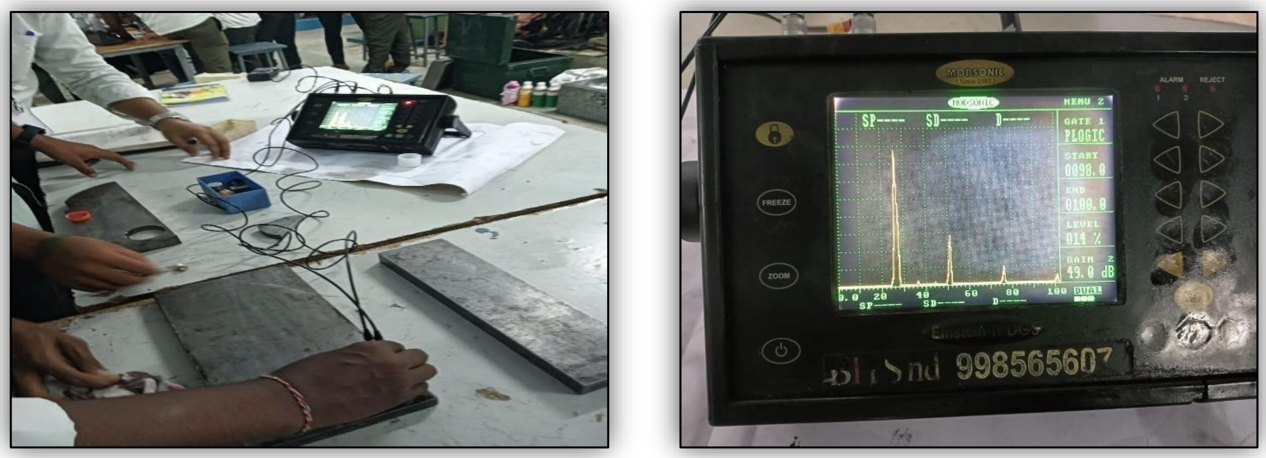


Fig 23: Comparison Method

Using the same settings, the reflector from the reference block is scanned which is approximately positioned at the same distance as the discontinuity, the quotative unit for evaluation is now the gain change of the ultrasonic instrument which is necessary to set the reference echo to the reference height

DISTANCE AMPLITUDE CORRECTION CURVE

FLAT BOTTOM HOLE

Test blocks containing artificial flaws consist of metal sections containing notches, slots, or drilled holes. These test blocks are more widely accepted as standards than are test blocks that contain natural flaws.

Test blocks containing drilled holes are widely used for longitudinal wave, straight- beam inspection. The hole in the block can be positioned so that ultrasonic energy from the search unit is reflected either from the side of the hole or from the bottom of the hole. The flat-bottom hole is used most because the flat bottom of the hole offers an optimum reflecting surface that is reproducible. A conical-bottom hole, such as is obtained with conventional drills, is undesirable, because a large portion of the reflected energy may never reach the search unit. Differences of 50% or more can easily be encountered between the energy reflected back to the search unit from flat-bottom holes and from conical-bottom holes of the same diameter. The difference is a function of both transducer frequency and distance from search unit to hole bottom. Figure 43(a) shows a typical design for a test block that contains a flat-bottom hole. In using such a block, high- frequency sound is directed from the surface called "entry surface" toward the bottom of the hole, and the reflection from it is used either as a standard to compare with signal responses from flaws or as a reference value for setting the controls of the ultrasonic instrument.

Fig 24: FBH Block

Reference blocks establish a standard of comparison so that echo intensities can be evaluated in terms of flaw size. Numerous factors that affect the ultrasonic test can make exact quantitative determination of flaw size extremely difficult, if not impossible. One factor is the nature of the reflecting surface. Although a flat-bottom hole in a reference block has been chosen because it offers an optimum reflecting surface and is reproducible, natural flaws can be of diverse shape and offer no uniform reflecting surfaces. The origin of a flaw and the amount and type of working that the product has received will influence the shape of the flaw. For example, a pore in an ingot might be spherical and therefore scatter most of the sound away from the search unit, reflecting back only a small amount to produce a flaw echo.

However, when worked by forging or rolling, a pore usually becomes elongated and flat and therefore reflects more sound back to the search unit.

On the screen, the height of the echo indication from a hole varies with the distance of the hole from the front (entry) surface in a predictable manner based on near-field and far-field effects, depending on the test frequency and search-unit size, as long as the grain size of the material is not large. Where grain size is large, this normal variation can be altered. the differences in ultrasonic transmissibility that can be encountered in reference blocks of a material with two different grain sizes. The austenitic stainless steel inspected. increasing the grain size affected the curve of indication height versus distance from the entry surface so that the normal increase in height with distance in the near field did not occur. This was caused by rapid attenuation of ultrasound in the large-grain stainless steel. In some cases where the grain size is quite large, it may not even be possible to obtain a back reflection at normal test frequencies.

The following should be considered when setting controls for inspection:

- Flaws of a damaging size may be permitted if found to be in an area that will be subsequently removed by machining or that is not critical

- It is generally recognized that the size of the flaw whose echo exceeds the rejection level usually is not the same as the diameter of the reference hole. In a reference: block, sound is reflected from a nearly perfect flat surface represented by the bottom of the hole. In contrast, natural flaws are usually neither flat nor perfectly reflecting
- The material being inspected may conduct sound differently from the material of the reference block. Normally, a reference block will be made from material of the same general type as that being inspected.

CHAPTER 6

TESTING PROCEDURE

Experimental procedure tests performed on lamination scanning with the knowledge of ultrasonic testing explained in above chapters, the sample of mild steel plate has been tested for identifying defects like lack of fusion, porosity, cracks, lamination defects... etc. has been observed

PROCEDURE STEPS:

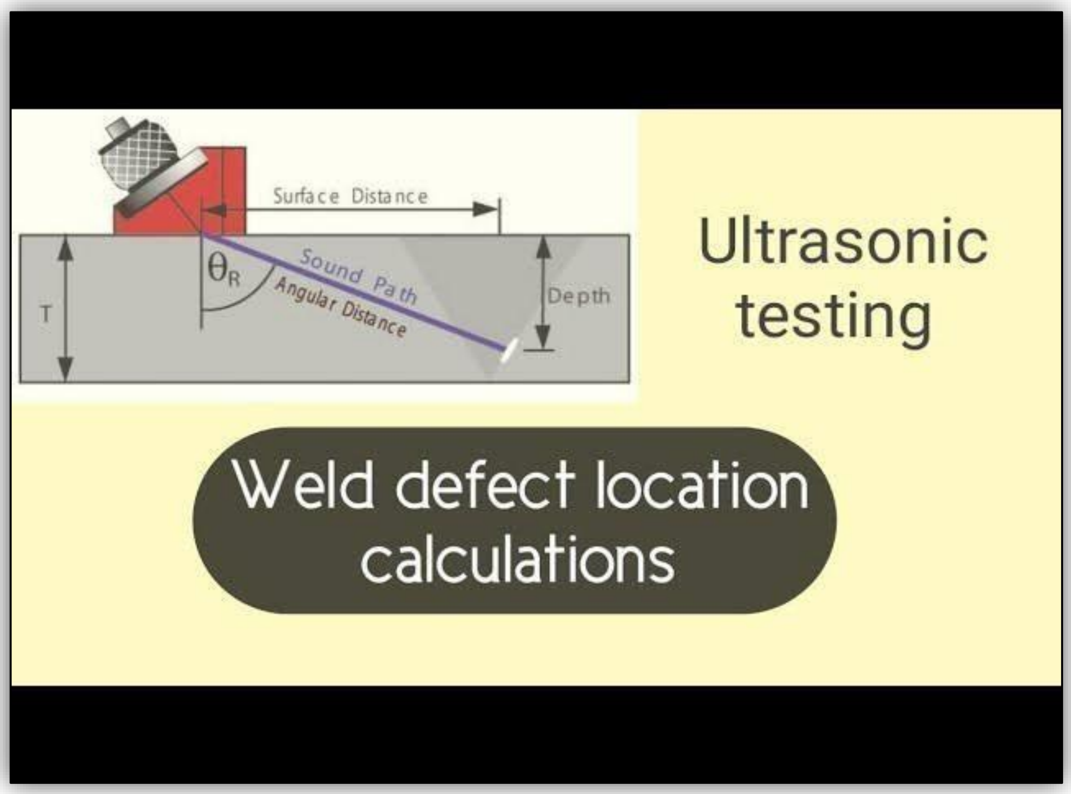
- **CALIBRATION**
- **DRAWING DAC CURVE**
- **TESTING ON WELDING JOINTS**

CALIBRATION OF BLOCK V1:

For calibration of the test instrument with an angle-beam probe the standard calibration block v1 and block v2 according to (BS 2704-A4),figure are almost exclusively used because no backwall echo sequence is received due to the angular beaming from a plane-parallel calibration block.

- Determining the sound beam exit point of an angle-beam search unit.
- Determining refracted angle produced.
- Calibrating sound path distance.
- Evaluating instrument performance.

The advantage with echoes from the circle segment of the calibration block is that the same sound path Is always given independent of the probe angle, we can see in the picture when the angle-beam probe is exactly coupled in the center of the circle segment,a first echo is exactly received from 100mm out v1 block. According to the reflection law, the sound waves coming out of the arc are reflected away from t the coupling surface to the back, this means away from the arc.



Different Probe Angles at V1 Block

A Second echo out of the arc, needed for the calibration sequence, cannot therefore be produced for this, there are two saw cuts made in the center of the quarter circle. In the edges, which these saw cuts from with the surfaces the sound waves are reflected back within themselves due to double reflection.

Because the radius of the circle segment is exactly 100mm we will regularly receive an echo sequence With distances 100mm, 200mm ,300mm etc. with which we are able to carry out calibration of the test Instrument the same way as the straight-beam probe.

ULTRASONIC WELD SCANNING

Fig 25: weld scanning

If measured values are mismatched with standard block values, then adjust zero in flaw detector to standard block values.

After adjusting zero draw DAC (DISTANCE AMPLITUDE CORRECTION CURVE).

Then proceed scanning on work piece under inspection and detect defects by observing echoes in flaw detector.

1. **RANGE:** Range =2*thickness of specimen

=2*20

=40mm

2. **PROBES**:T-R/DUAL PROBE

Frequency of probe is 5MHZ

Transmitter-receiver probe with contact diameter 10mm.

Piezoelectric material probes are used, because a piezoelectric material has the ability to produce ultrasonic sounds and satisfies re visibility property.

Fig 25: Single Probe

3. EQUIPMENT USED:

MACHINE: ULTRASONIC FLAW DETECTOR (UFD)

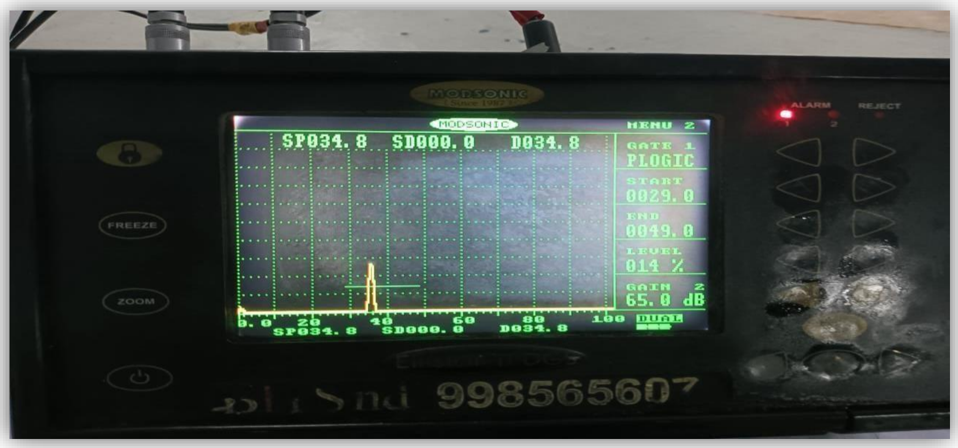


Fig 26: Flaw Detector

PROBE: DUAL /T-R PROBE

MODEL: EINSTIN-DGS

MAKE: MODOSONIC

4. VELOCITY: dual probe produces LONGITUDINAL WAVES with velocity 5920 m/s.

5. SIZEUP METHOD: Equalization method is selected for marking defected areas in work specimen. Defects are marked between two echoes" (defect indicating echo and final echo) at equal amplitude levels.

6. REFERENCE CURVE USED FOR ANALYSIZING THE INTENSITY OF DEFECT: DAC curve is draw by using FBH Block (FLAT BOTTOM HOLE).

CHAPTER 7

ULTRASONIC WELD SCANNING EVALUATION

Referance curve is used for analyzing the intensity of defect and consider DAC Curve.In this test SDH Block is used as the Standard block.

ANALYSIS OF WELDMENT:

Thickness of weldment T = 20mm

1. **Probe Angle =** 90-T

   = 90-20

   =70(consider 70 Angle Probe)

2. **Half Beam path =** $T/\cos\theta$

   = 20/cos70

   = 31.5mm

3. **Full Beam path** = $2T/\cos\theta$

   = 2×20/cos70

   = 116mm

4. **Range** = FBP×1.25

   = 116×1.25

   = 145mm

5. **Half Skip Distance** = $T.\tan\theta$

   = 20×tan70

   = 55mm

6. **Full Skip Distance** **=** $2T\times\tan\theta$

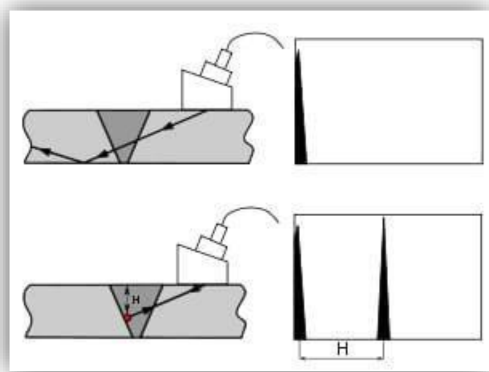
   = 2×2×Tan70

   = 55mm

EVALUATION AND TEST REPORT

SPECIMEN REFERANCE NUMBER	**MI-16-01-HSV-156**
SPECIMEN LENGTH & THICKNESS	**300mm&20mm**
JOINT TYPE AND CONFIGURATION	**SINGLE V BUTT JOINT**
EQUIPMENT USED	**ULTRASONIC FLAW DETECTOR**
REFERANCE REFLECTOR TYPE/ SIZE	**SDH BLOCK/3MM DIAMETER**
TRANSDUSER USED & ANGLES	**0 DEG,45 DEG, 60 DEG,70 DEGREES**
REFERANCE GAIN SETTING	**69.5MM**
COUPLANT USED	**LUBRICATING OIL**

REFLECTOR LOCATION SKETCH 1:



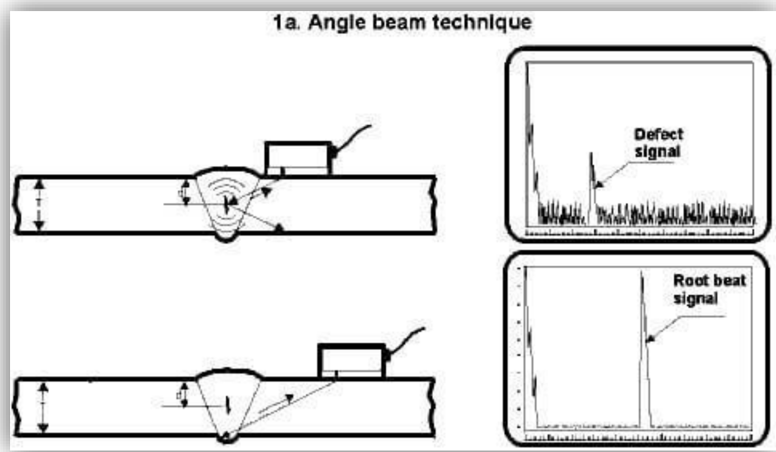
DEFECTS OF M1-16-05-HSV-156

S.NO	FLAW TYPE	DISTANCE FROM-0(MM)	FLAW LENGTH(MM)	FLAW DEPTH(MM)	ANGLE
1	LACK OF FUSION-1	42	20	13.2	70
2	SLAG	200	18	15.8	70

3	LACK OF FUSION-2	110	18	6.8	70

From the above ultrasonic report 1, it is observed that the defects are lack of fusion-1 length is 20mm, Lack of Fusion-2 length is 18mm and slag length is 18mm.

REFLECTOR LOCATION SKETCH 2:



S.NO	FLAW TYPE	DISTANCE FROM-0(MM)	FLAW LENGTH(MM)	FLAW DEPTH(MM)	ANGLE
1	FUSION	52	24	4.2	70
2	ROOT CRACK	170	26	16.5	70

From above ultrasonic report 2, it is observed that the defects are lack of fusion-1 length is 24mm,root crack length is 26mm.

CHAPTER 8
CONCLUSION

This project aims at introducing inspection and various testing methods to understand its purpose and importance in industries especially in fabrication industries.

After studying various non-destructive inspections and testing techniques, their applications, advantages and limitations, it can be concluded that it is a very important tool for the modern industries. we selected ULTRASONIC TESTING TECHNIQUE for detecting WELDED defects in MILD STEEL PLATE by using SINGLE PROBE. this technique is further used for detecting defects like cracks.porosity etc., in WELDED JOINTS by using ANGULAR PROBE.

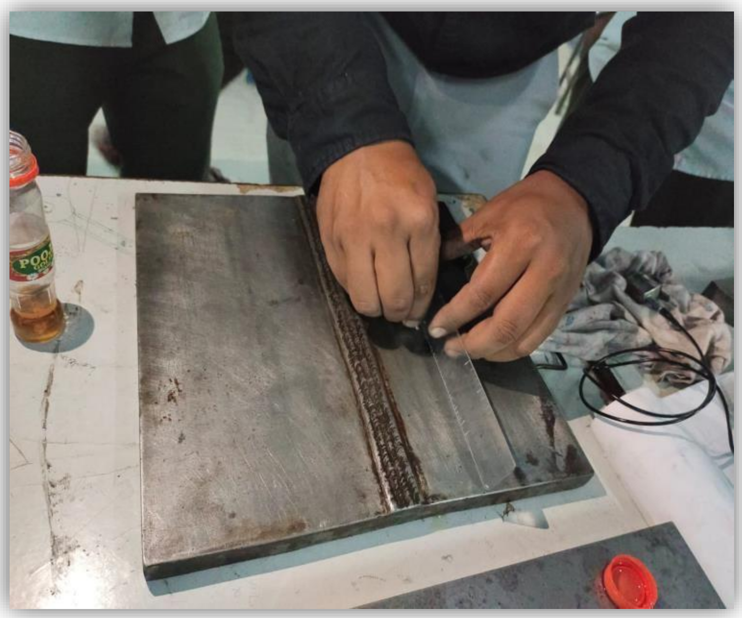
CHAPTER 9

REFERENCES

1. AJ. Krautkramer and H. Krautkramer, Ultrasonic Testing of Materials, 1st end, Springer-Verlag, 1969.
2. D. Ensminger. Ultrasonic, Marcel Dekker, 1973.
3. Y. Bar-Cohen, NDE of Fibre Reinforced Composites--A Review, Mater. Eval Vol 44 (No. 4), 1986, p 446-454.
4. Y. Bar-Cohen, Non-destructive Characterization of Defects Using Ultrasonic Backscattering, in Ultrasonic International 87, Conference Proceedings, Butterworth, 1987, p 345-352.
5. R. Helmsman, Non-destructive Testing. Edward Arnold, 1987, p 198, 143,211.
6. Y. Bar-Cohen and A.K. Mal, Leaky Lamb Waves Phenomena in Composites Using Pulses, in Review of Progress in Quantitative NDE, Vol 8, D.P. Thompson and D.E. Chimenti, Ed. Plenum Press, 1989.
7. A.K. Mal and Y. Bar-Cohen, Ultrasonic Characterization of Composite Laminates, in Wave Propagation in Structural Composites, Proceedings of the joint ASME and SES meeting, AMD-Vo190, A.K. Maland, T.C.T. Ting. Ed., American Society of Mechanical Engineers, 1988, p 1-16.
8. Loizos and Papavasiliou (2006) performed a comprehensive monitoring and data analysis research study by using Falling Weight deflect meter (FWD) for in situ evaluation of recycled pavements.
9. prover bio and Venturi (2005) evaluated the reliability of rebound hammer test and UPV test on concrete of different composition and strength.
10. Rens et al. (2005) explained application of NDE methods for bridge inspection, which is Bridge Evaluation Using NDT (BENT).
11. Malave et al. (2003) used pull off tests to evaluate effects of temperature, moisture, and chloride content on CFRP adhesion.
12. Pascal et al. (2003) carried out an experimental program involving both destructive and non-destructive methods applied to different concrete mixtures.
13. Almir and Portacio (2000) used NDT methods to determine the compressive strength of concrete relationship between the measured mechanical or physical properties and the strength and also presented the validity of pull off, pin penetration, and UPV for assessing the concrete strength.
14. Chen et al. (1995) presented findings of research on fibres optic Bragg gratings as stress/ strain sensors for monitoring the critical sections of composite beams.

CHAPTER 10

WORKING PHOTOS

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