Seminar Presentation
on
Major Project:

DETECTION & CHARACTERIZATION OF DEFECTS IN WELD JOINTS BY USING ULTRASONIC NON-DESTRUCTIVE TESTING TECHNIQUE

Under the Guidance of
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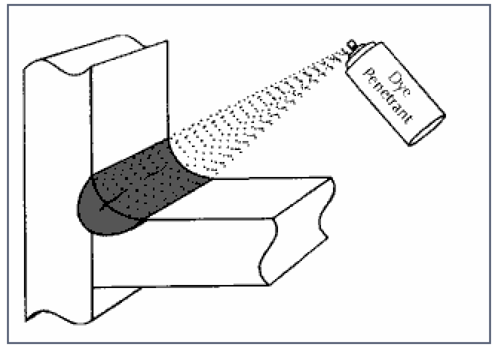
Purpose of Weld Inspection

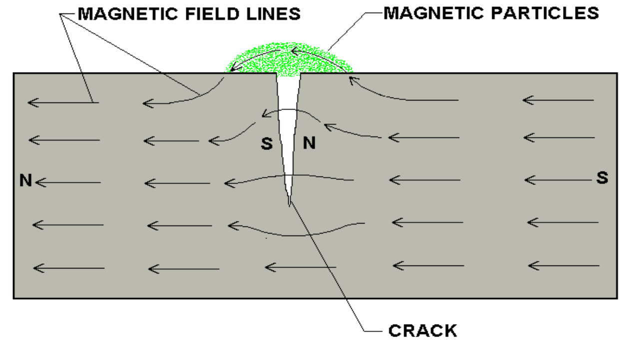
- There is a high occurability of surface and internal defects in the weld zone due to numerous variables in welding process.
- The strength of the weld joint is depends not only on the presence or absence of the defects in weld zone but also their size, location and distribution.
- Therefore, detecting various defects in the weld zone and quantitative evaluation are of great importance in terms of the structure's integrity and stability.

Common NDT Methods

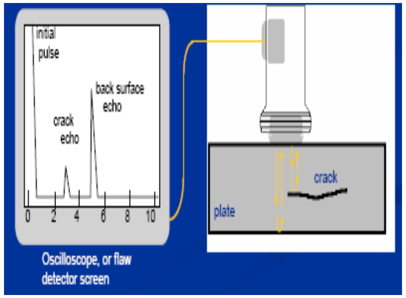
Visual testing



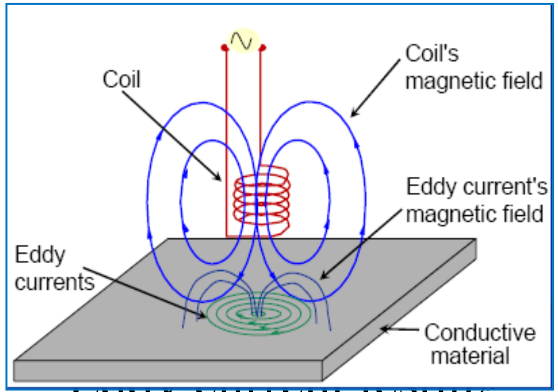
Liquid Penetrant testing

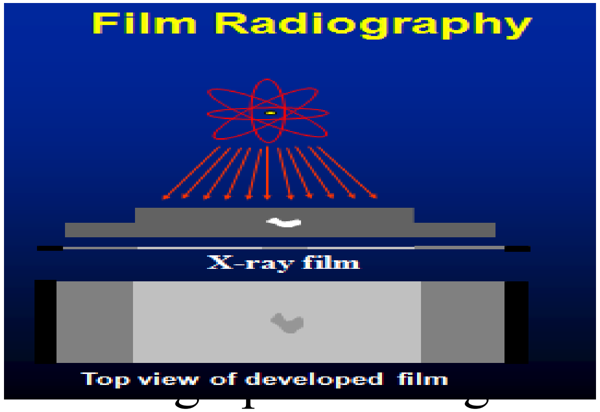


Magnetic particle testing



Ultrasonic testing





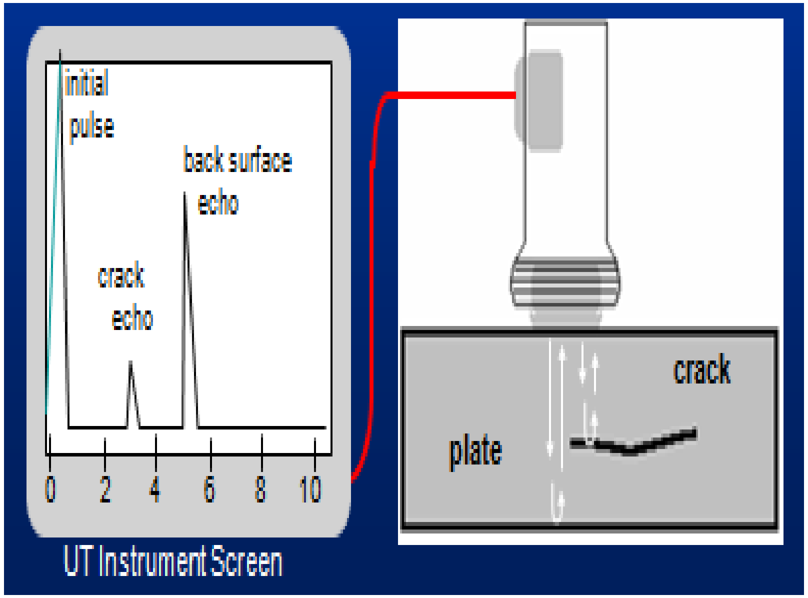
Introduction of UT

- In Ultrasonic testing, a beam of ultrasonic waves is directed into the object to detect and locate internal defects or discontinuities. When the ultrasonic waves are directed into the object, they reflected not only at the interfaces but also by internal flaws.

- A receiver probe picks up the reflected ultrasonic waves and displayed in the form of echo on CRT screen. The analysis of this signal is done to locate the flaws in the object under inspection.

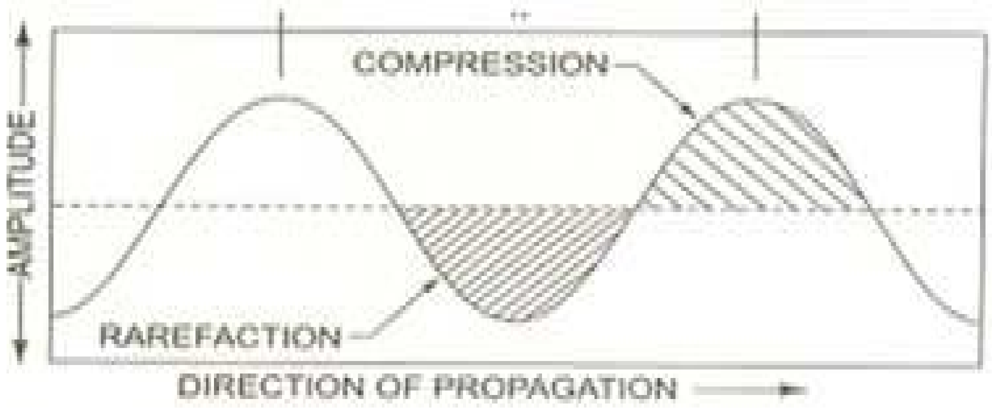
- Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization etc.

Basic Principle of UT

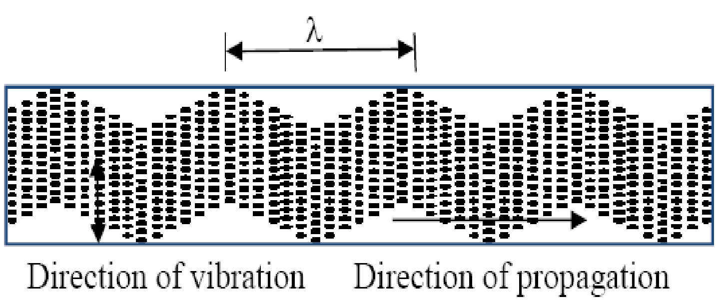


- The basic principle of ultrasonic testing is based on the theory of acoustic impedance mismatch.
- If the material is sound, its means that there is no impedance mismatch. In such case ultrasonic waves travels at uniform velocity and reflected only at the boundary of the material.
- If there is impedance mismatch in the material, ultrasonic waves reflected not only at the boundary of the material but also at the boundary of the flaw.
- Receiver probe picks up these reflected waves and displayed on CRT screen in the form of echoes. These signals are used for quantitative evaluation of flaws.

Ultrasonic Waves



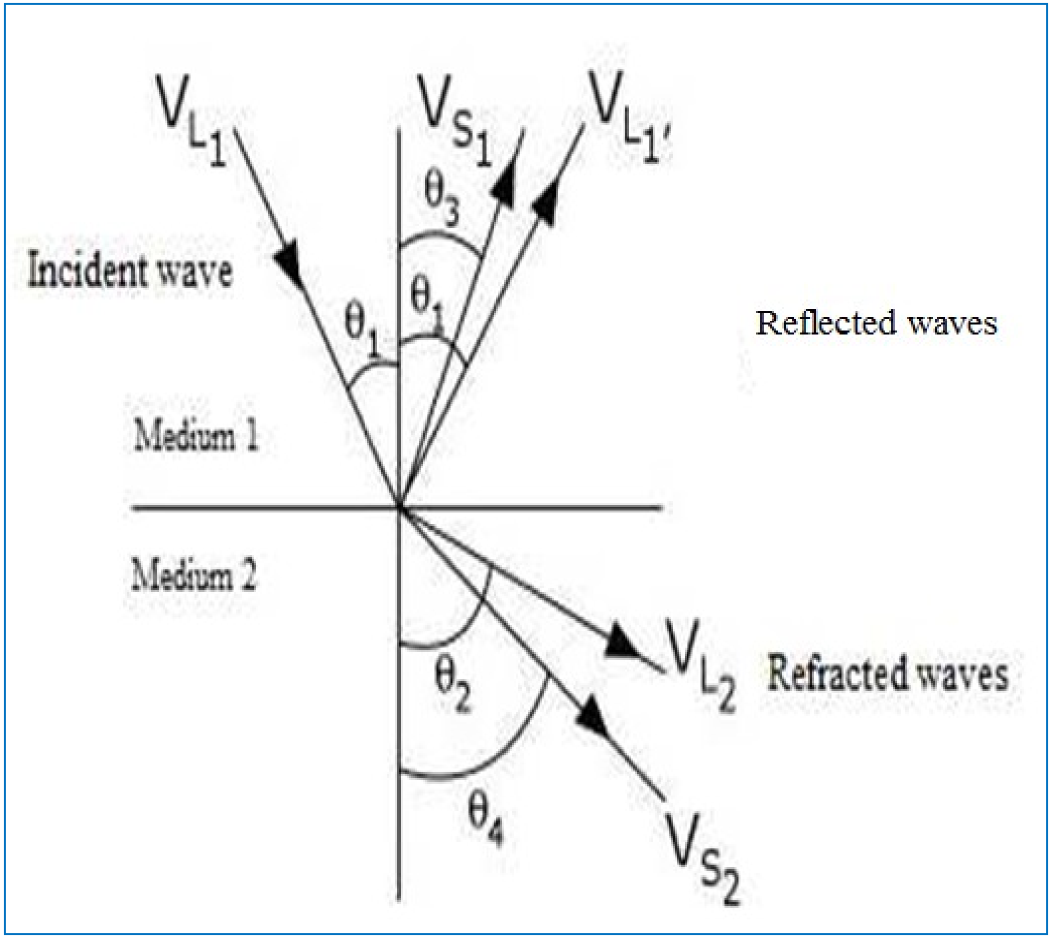
Longitudinal waves:



Shear waves:

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

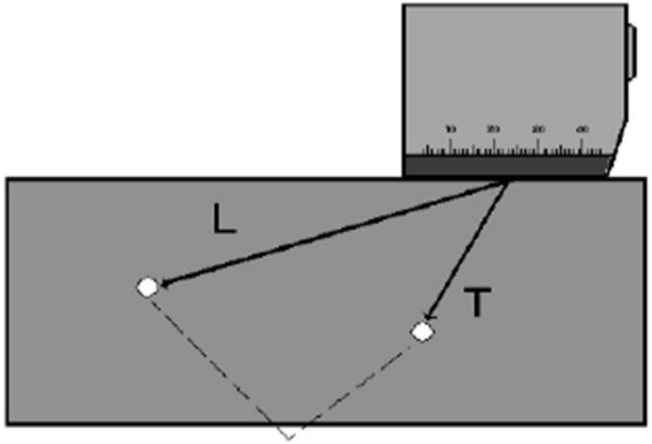
Properties of Ultrasonic Waves:



Mode conversion

- Reflection
- Refraction
- Mode conversions
- Attenuation

Effect of Mode Conversion



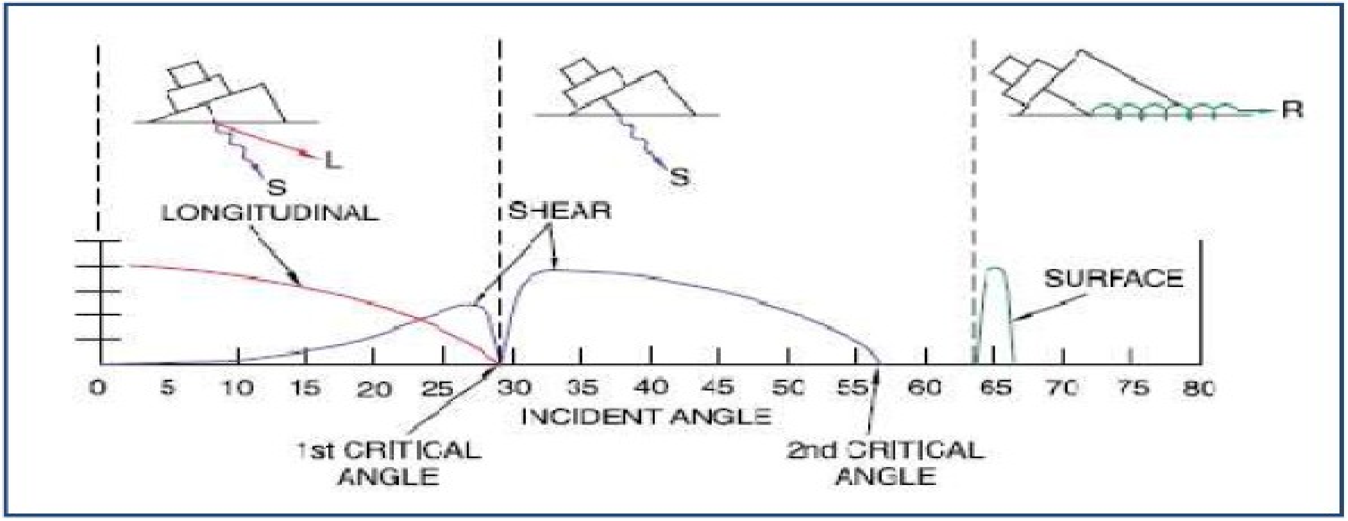
- Since mode conversion will introduced two waves of different velocities and angles into the test material, the results will be confusing. Hence, it is required to eliminate one of them.

- The phenomenon of mode conversion depend on following parameters-

- The angle of incidence
- Acoustic impedances of the materials
- Velocity of the wave

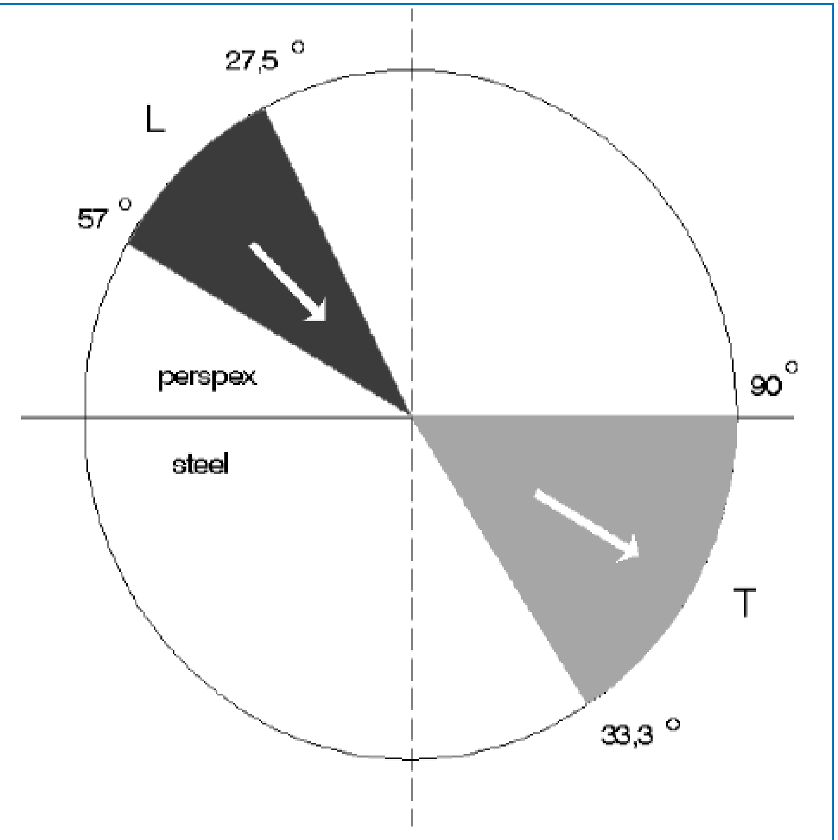
Critical Angles for Ultrasonic Waves

- **First Critical Angle & Second Critical Angle**



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

Usable range of angle probes:



Usable range for angle-beam probes in steel

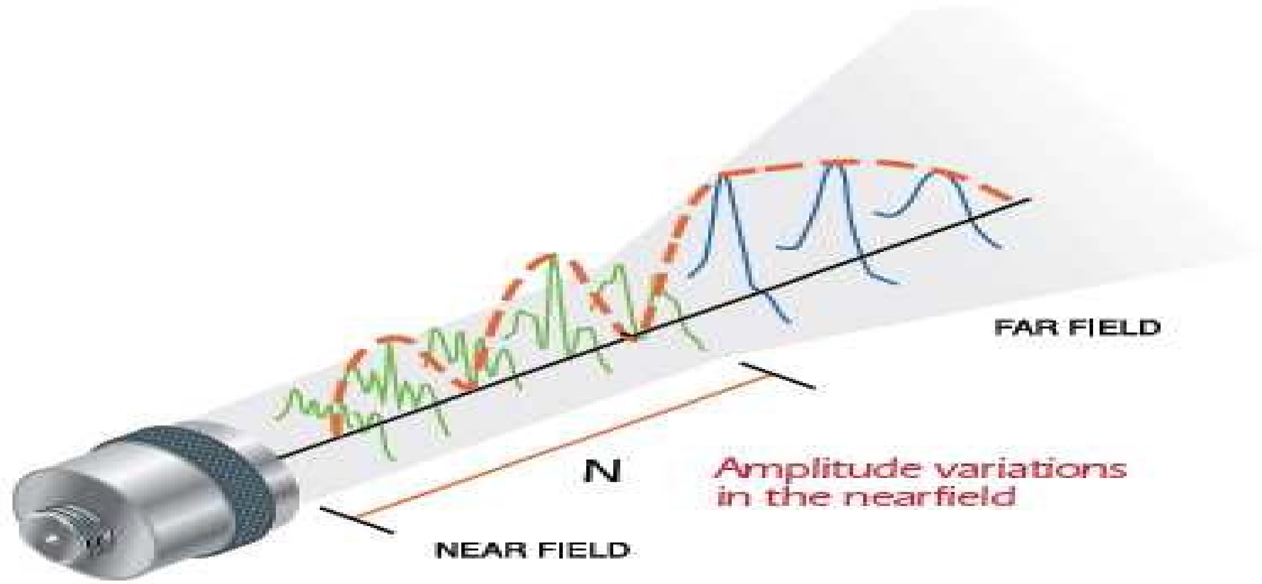
- The area in which an angle of incidence is present between the 1st and 2nd critical angle (27.5° - 57°) gives us a clear evaluable sound wave in the test object .
- For Perspex/steel interface

  First critical angle = 27.5° and corresponding refracted angle = 33.3°

  Second critical angle = 57° and corresponding refracted angle = 90°

Characteristics of Ultrasonic Beam:

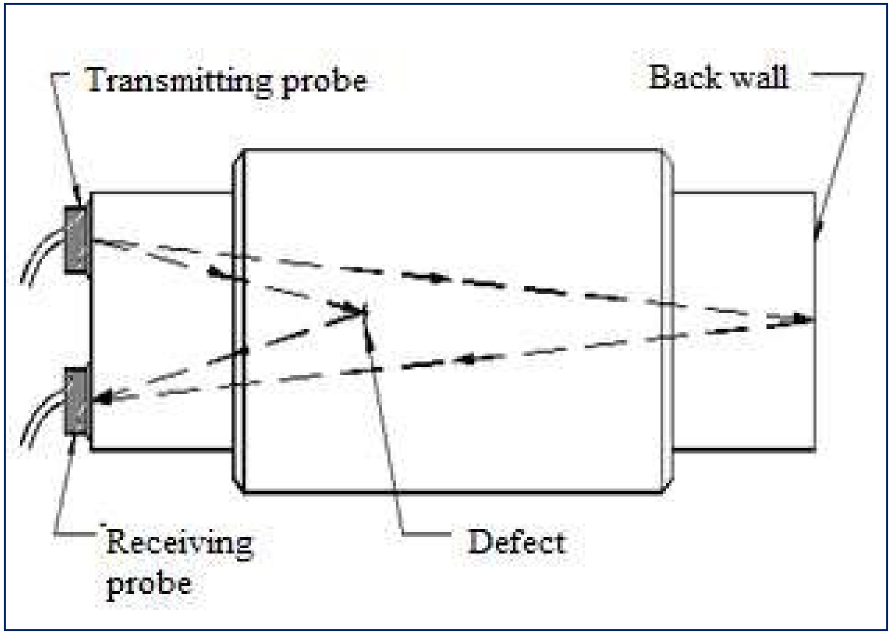
- A sound beam can be roughly divided into two regions-
  - Near field
  - Far field

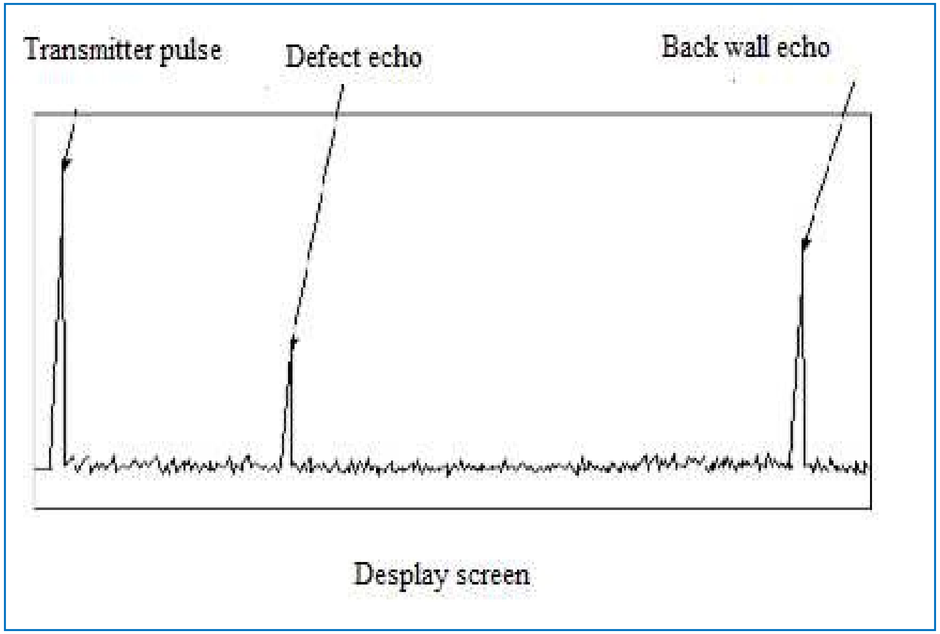


Pulse Echo Ultrasonic Testing Technique

- This method utilizes the reflected part of the ultrasonic waves. In this method, the transmitter and receiver probes are on the same side of the specimen.

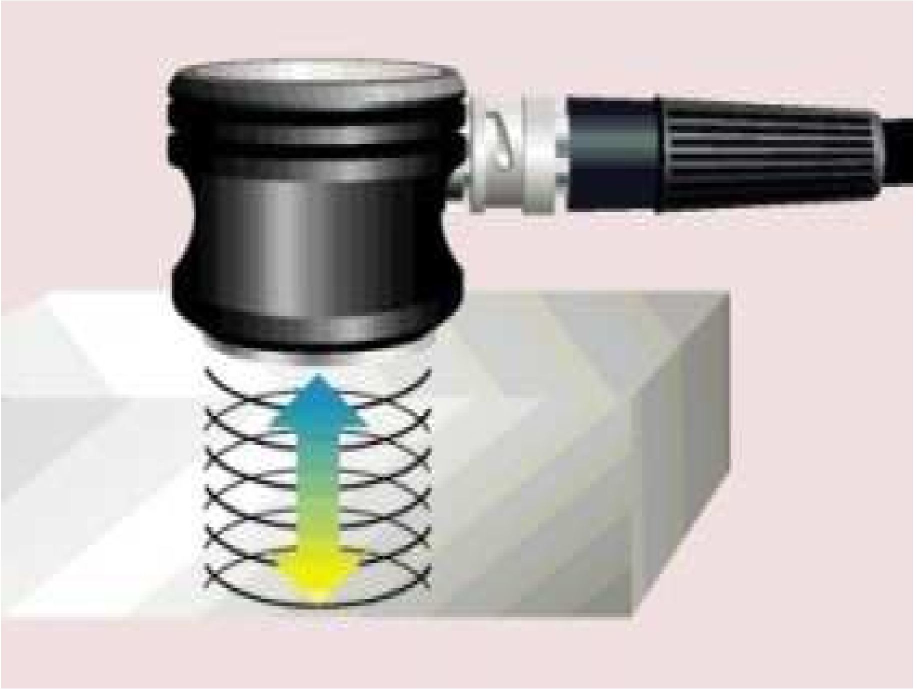
- The presence of a defect is indicated by the reception of an echo before that of the backwall echo.

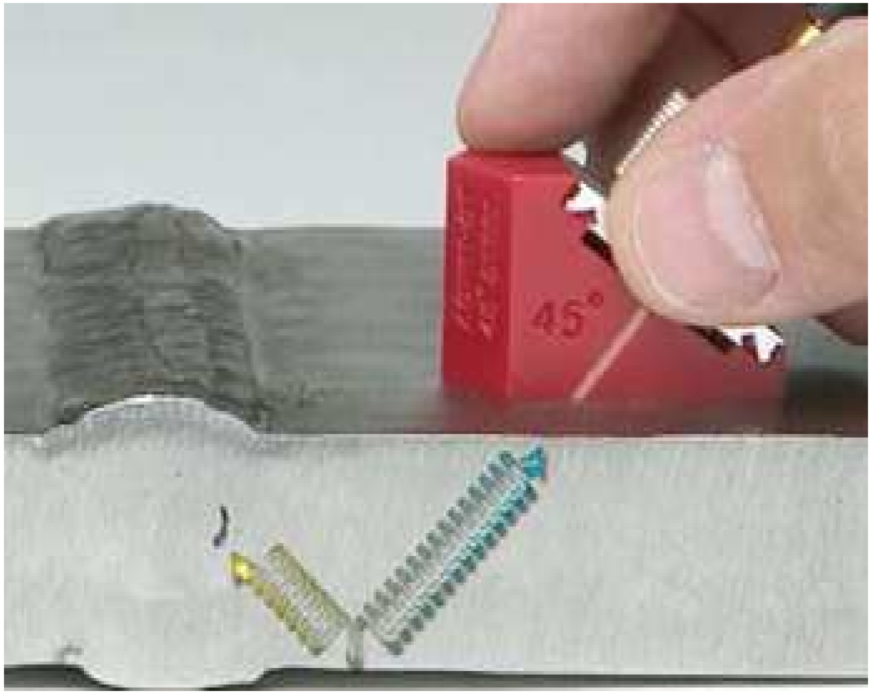




Pulse Echo Testing Methods

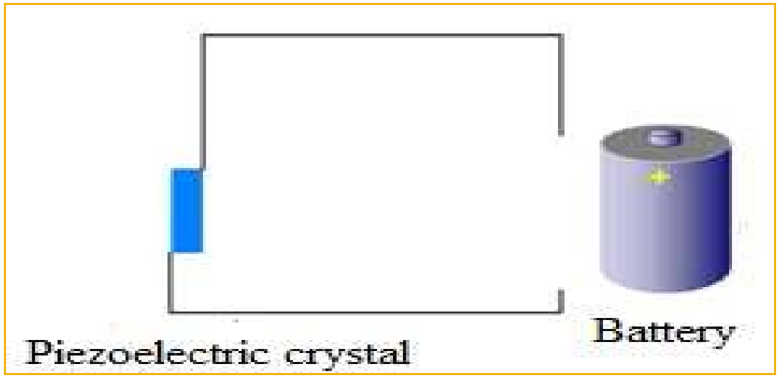
NORMAL BEAM TESTING | **ANGLE BEAM TESTING**

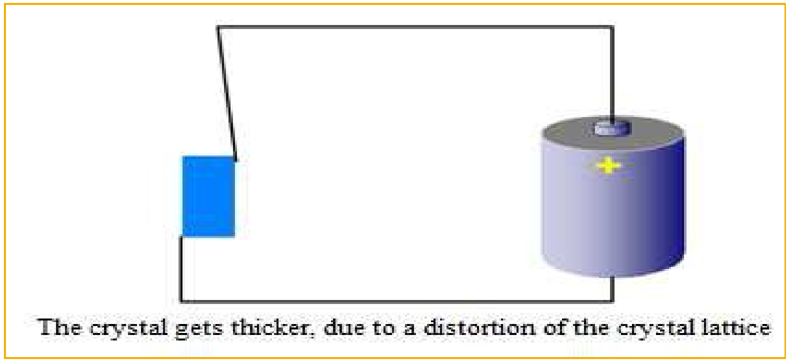


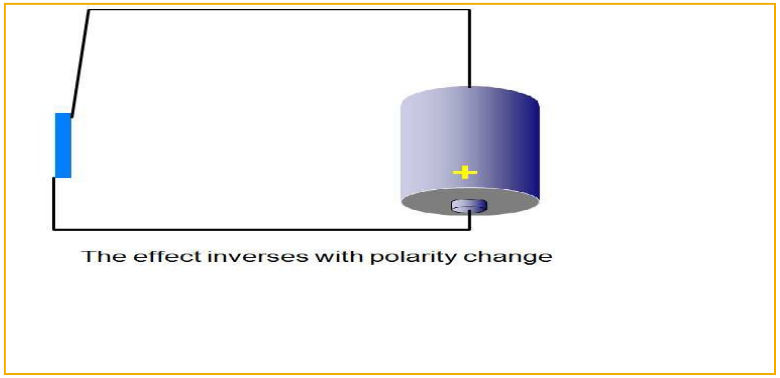


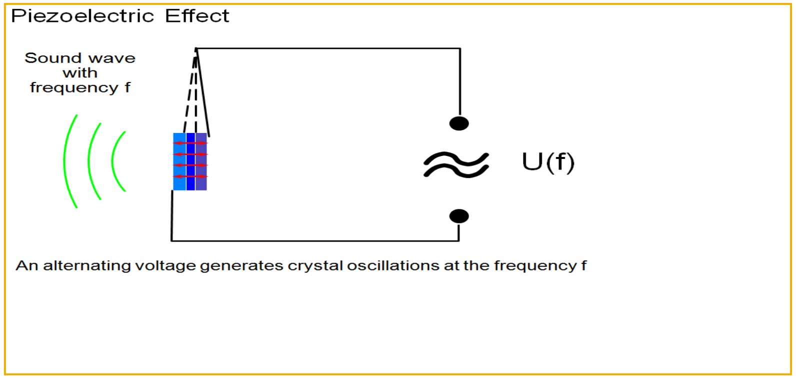
Equipments for Ultrasonic Testing.....
1- Ultrasonic Probe

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



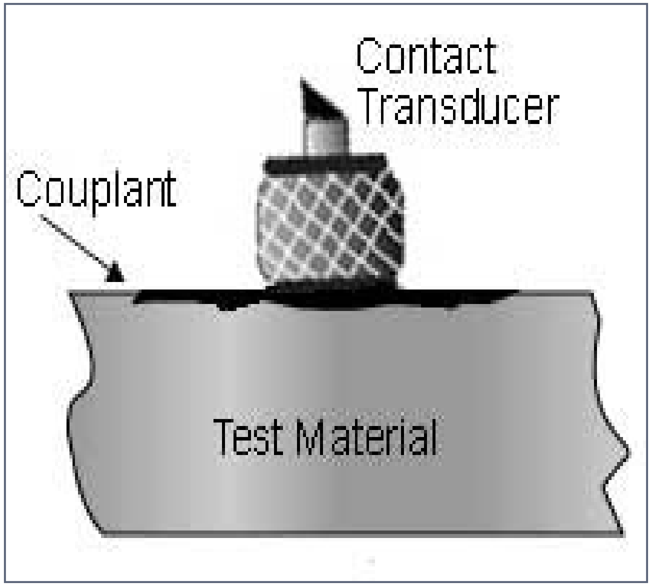






Equipments for Ultrasonic Testing…..

2- Acoustic Couplant



- In UT acoustic couplant is required because of..

  - Air is a poor transmitter of sound waves at megahertz frequencies.

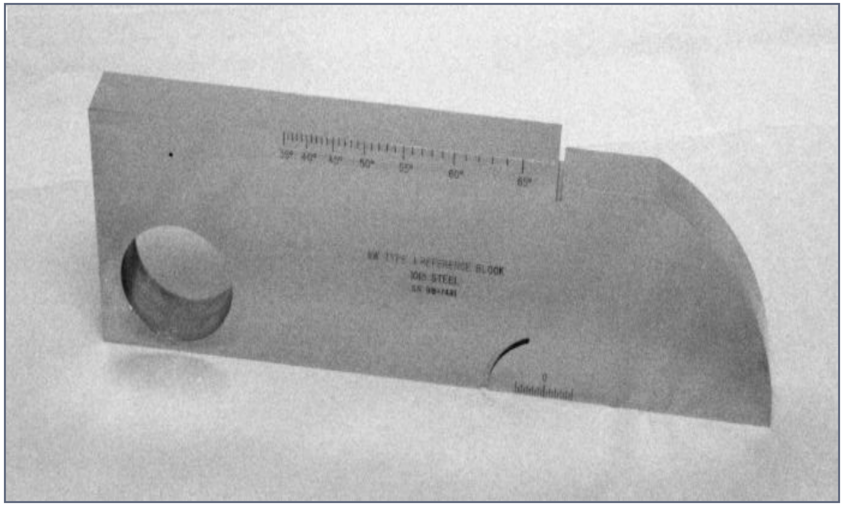
- To perform satisfactory contact inspection it is necessary to eliminate air between the Probe and the test piece. This is done by using a couplant.

- Couplants normally used for contact inspection are water, oils, glycerin, petroleum greases.

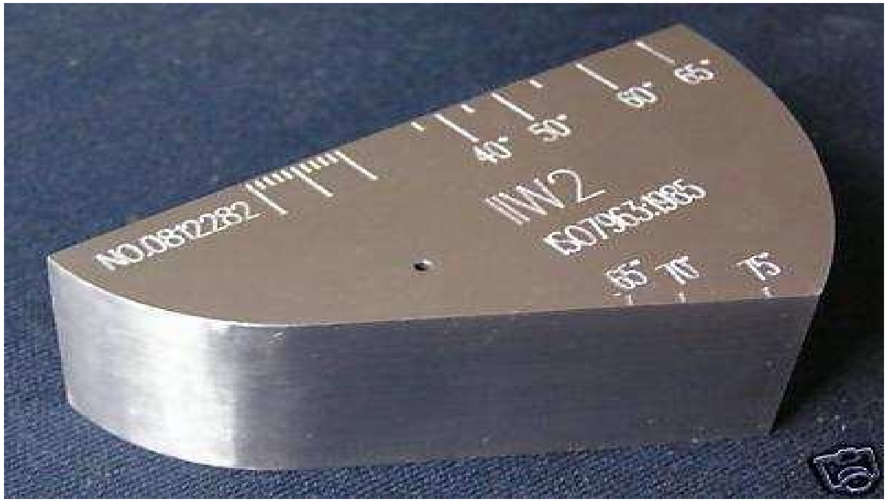
Equipments for Ultrasonic Testing.....

3-Calibration and Reference Blocks

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



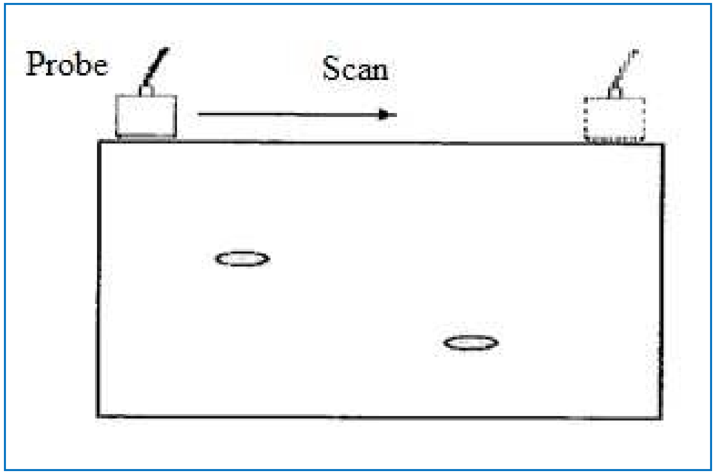
IIW(V1)

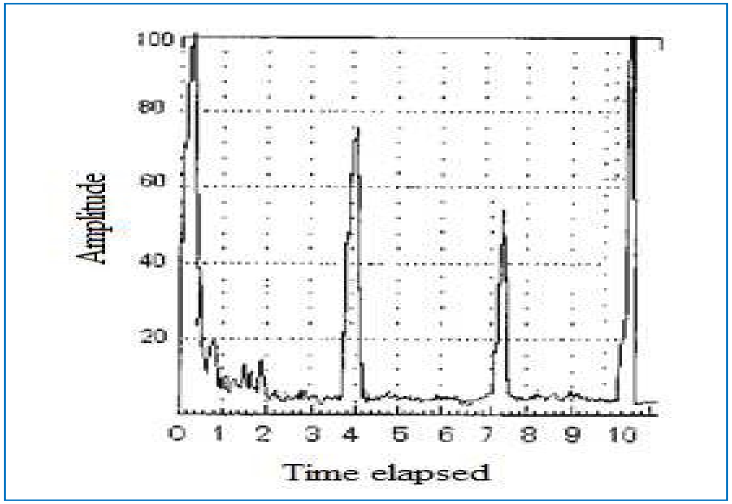


IIW(V2)

Equipments for Ultrasonic Testing...

4- Ultrasonic Data Presentation





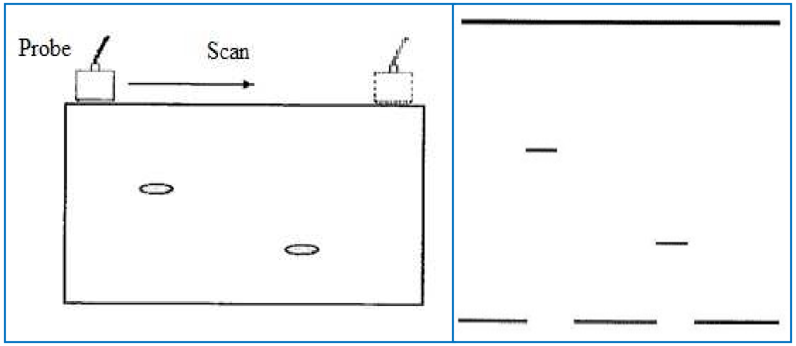
A- Scan Presentation:

- The A-scan presentation displays the amount of received ultrasonic energy as a function of time. The relative amount of received energy is plotted along the vertical axis and the elapsed time is displayed along the horizontal axis.

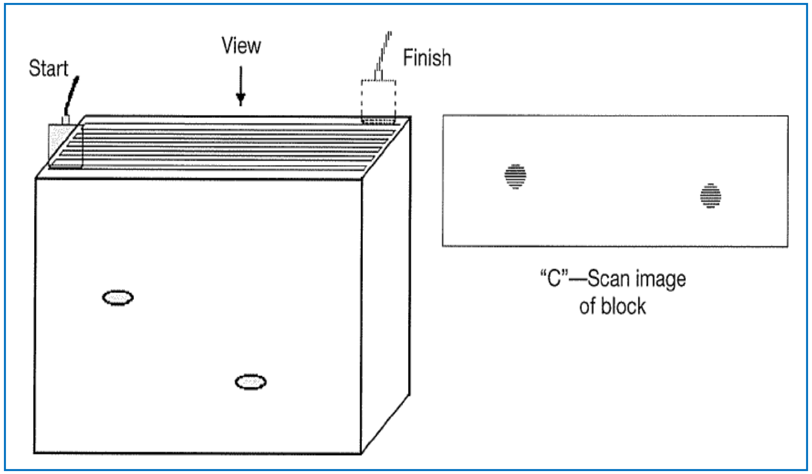
- In the A-scan presentation, relative discontinuity size can be estimated by comparing the signal amplitude obtained from an unknown reflector to that from a known reflector.

- Reflector depth can be determined by the position of the signal on the horizontal axis.

Equipments for Ultrasonic Testing...
Ultrasonic Data Presentation



B- Scan Presentation



C- Scan Presentation

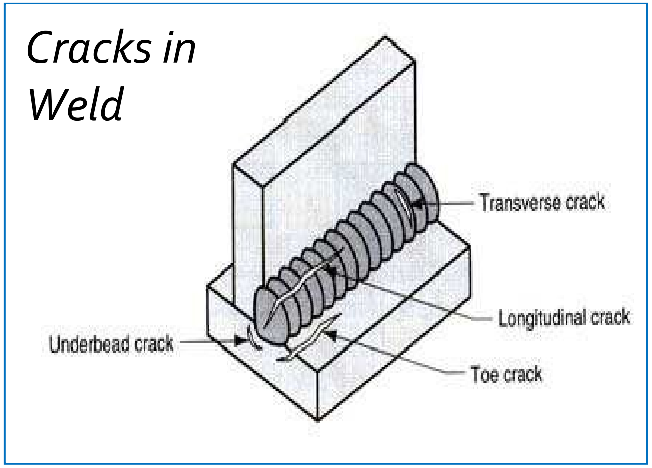
- **B-Scan Presentation:**

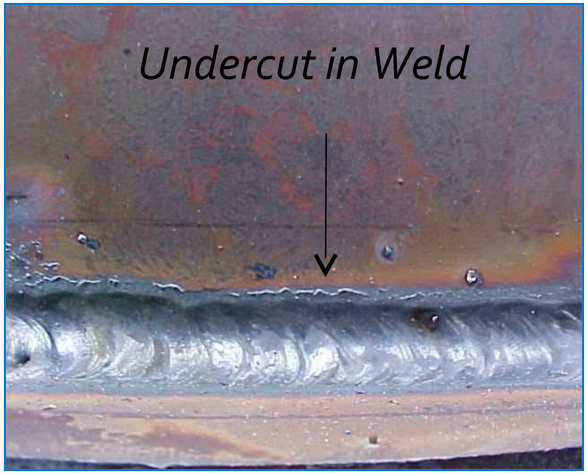
  The B-scan presentation is shows a cross-sectional view of the test specimen.

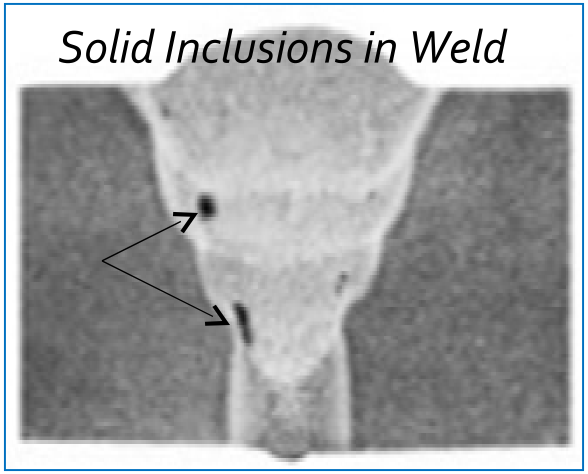
- **C-Scan Presentation:**

  The C-scan presentation provides a plan-type view of the location and size of test specimen features.

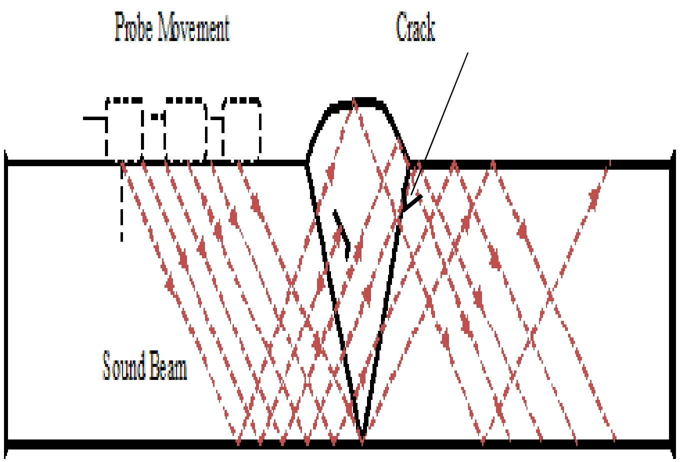
Common Welding Defects







Inspection of Welds

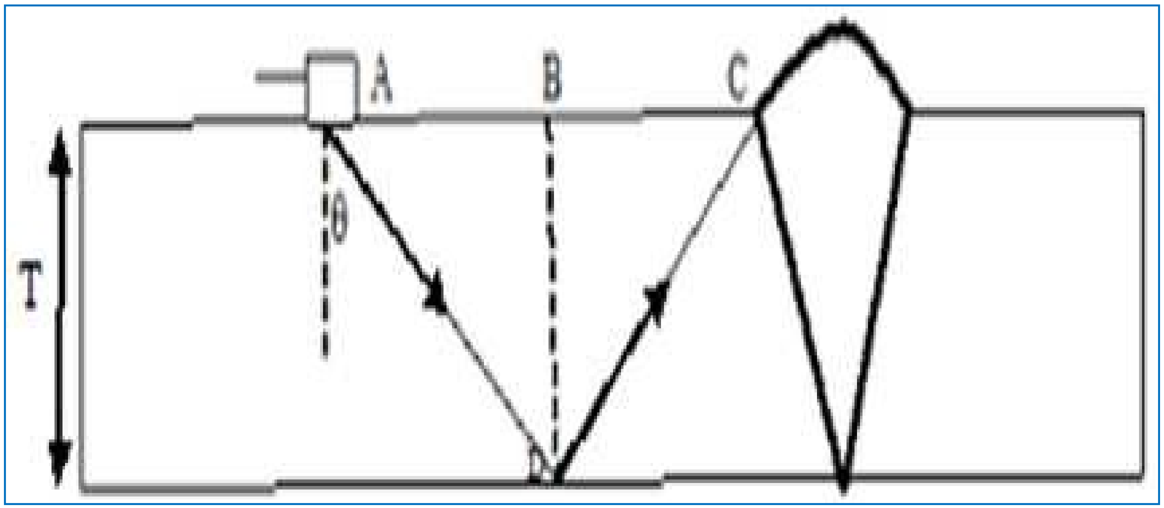


Inspection of Welds

- The inspection of a weld is carried out by an angle beam probe which is used to introduce shear waves in the component to be tested.
- The process involves scanning the surface of the material around the weldment with the ultrasonic probe.
- If the weld zone is defect free, there is no echo indication on the CRT screen.
- Echo indication occurs when and only when weld zone have some defects as shown in fig.

Beam Path and Skip Distance of the Weld

- To determine the proper scanning area for the weld, the inspector must first calculate the position of the probe with respect to the weld zone.

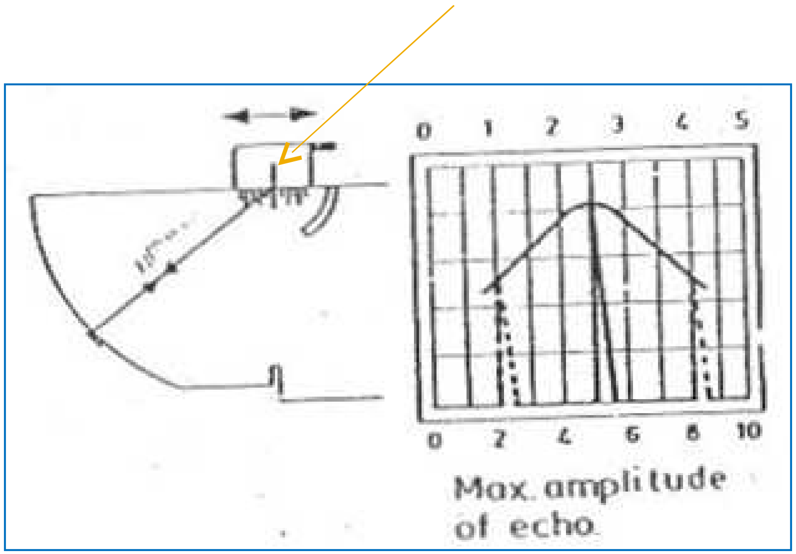


Distance AB	=	Half – Skip- Distance	=	$T \tan\theta$
Distance AC	=	Full – Skip- Distance	=	$2T \tan\theta$
Distance AD	=	Half Metal Beam Path	=	$T \sec\theta$
Distance AD + DC	=	Full Metal Beam Path	=	$2T \sec\theta$

Where θ = Probe angle

Calibration of the Instrument.......

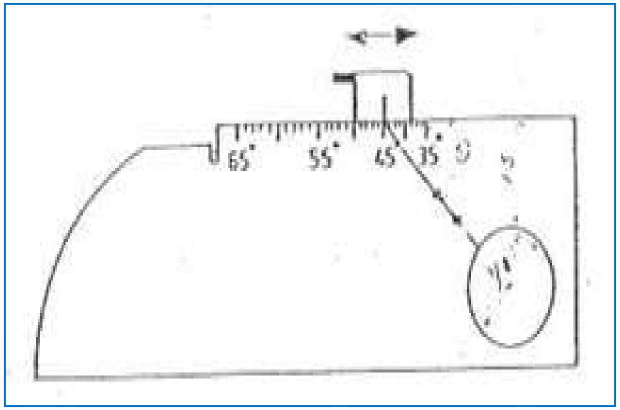
1- Measuring the probe index



- Place the angle probe on the IIW block as shown in figure in such a way that the beam is directed towards the curvature forming the 100mm radius.
- Move the probe to & fro and find out the position giving the maximum echo amplitude. Mark a sign at the centre of 100mm radius.
- With the help of above sign, also mark a sign on the probe. This gives the required probe index.

Calibration of the Instrument…….

2- Measuring Probe Angle



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

- Place the probe on the angles sides as marked on the calibration block.
- Move the probe to & fro manner till maximum echo amplitude is obtained.
- As soon as you got an echo of maximum amplitude, stop the probe movement and compare the angle marked on the calibration block with the probe index point (already marked on the probe).
- The angle marked on the V1 block, corresponding to the probe index point, is the angle of the probe.

Calibration of the instruments.....

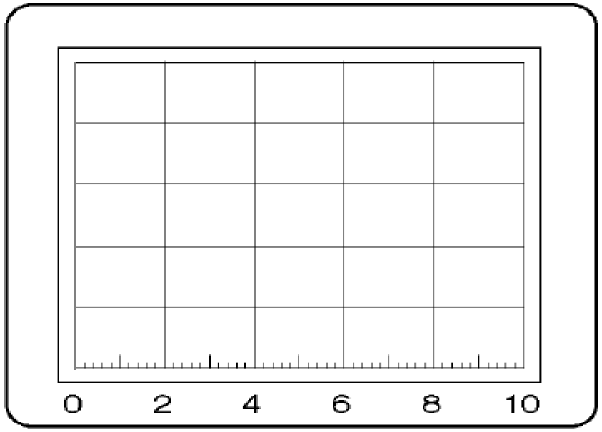
3-Range Calibration

- Place the probe on the IIW (V1 or V2) block to obtain two echoes of maximum amplitude from the curved surface.
- If these echoes are comes at there respective position, range is calibrated.
- If these echoes are not comes at there respective position, shift echoes at there respective position with the help of control knob.
- Generally CRT screen has 10 big divisions and one big division is divided into 5 small divisions as shown in figure.

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

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

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



CRT Screen

Range calibration with IIW (V2) block

Case: 1 - Facing 50R face.

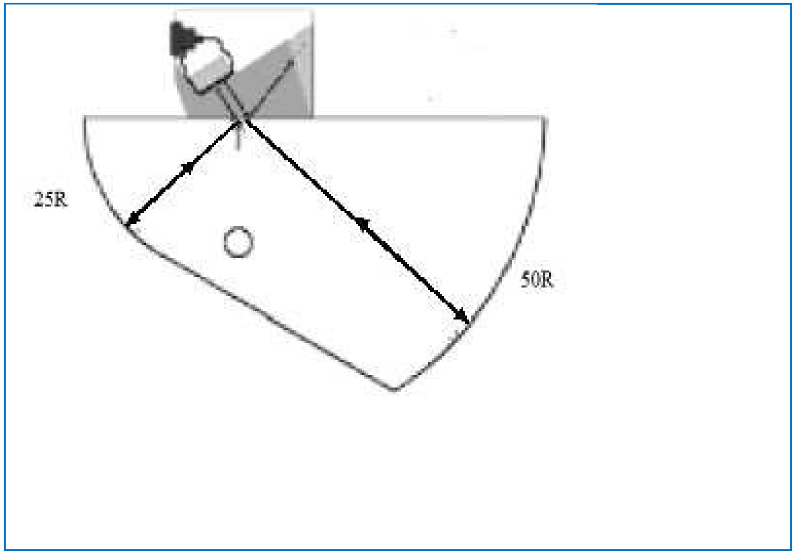
- 1st echo distance = 50mm (R)
- 2nd echo distance = 125mm (R)
- 3rd echo distance = 200mm (R)
- 4th echo distance = 275mm (R)

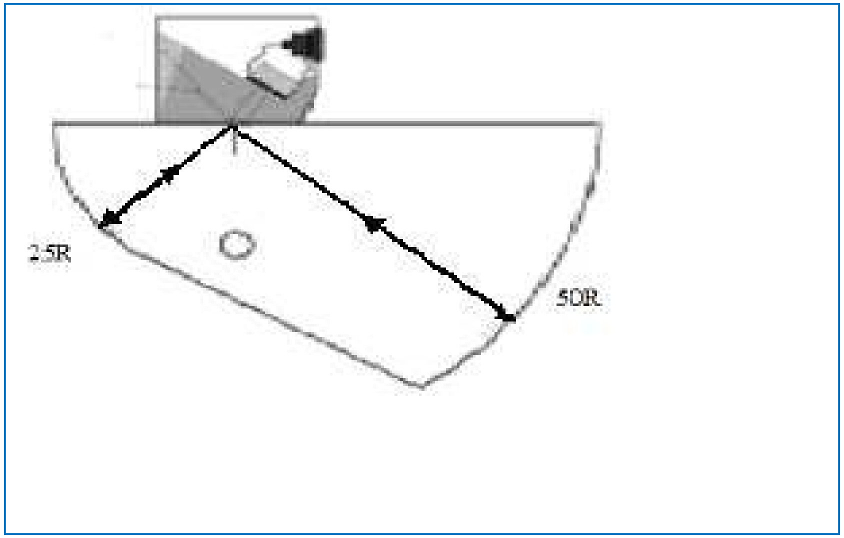
  and so on.

Case: 2- Facing 25R face.

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

  and so on.





Calibration of the range 0 – 150 mm by facing the 25R face of V2 block

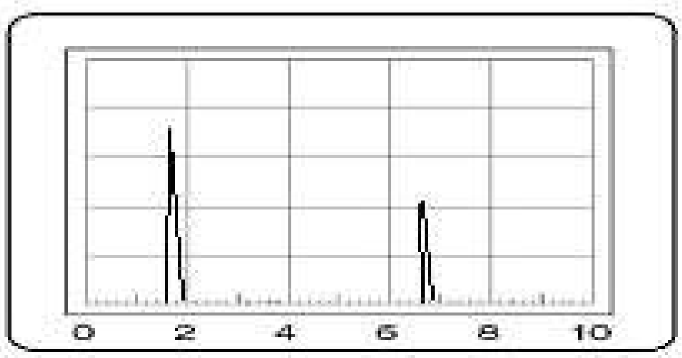
For 0 – 150 mm range

One Big division = 150/10 = 15

One small division = 15/5 = 3

Facing 25R face of the V2 calibration block

- 1st echo position = 25/ 15 = 1 big division and, 10/3 ≈ 3 small divisions
- 2nd echo position = 100/15 = 6 big divisions and, 10/3 ≈ 3 small divisions



CRT Screen

Calibration of the range 0 – 150 mm by facing the 50R face of V2 block

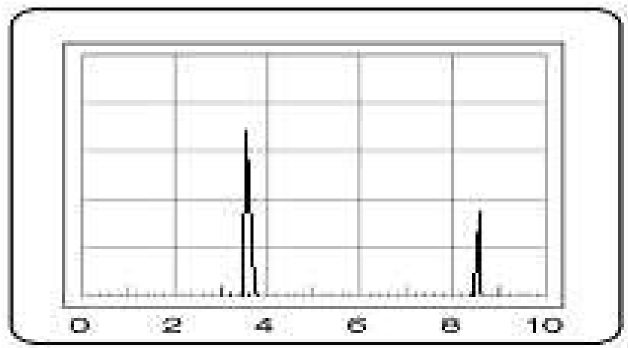
For 0 – 150 mm range

One Big division = 150/10 = 15

One small division = 15/5 = 3

Facing 50R face of the V2 calibration block

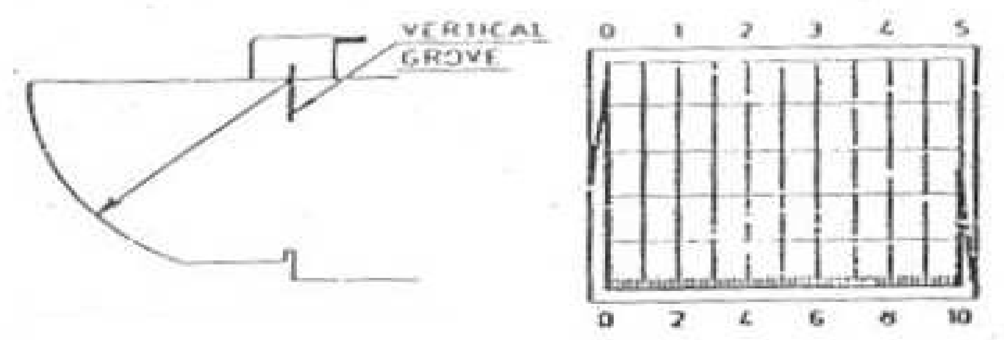
- 1st echo position = 50/15 = 3 + 5/3 ≈ 3 + 2 = 3 big divisions + 2 small divisions
- 2nd echo position = 125/15 = 8 + 5/3 ≈ 8 + 2 = 8 big divisions + 2 small divisions



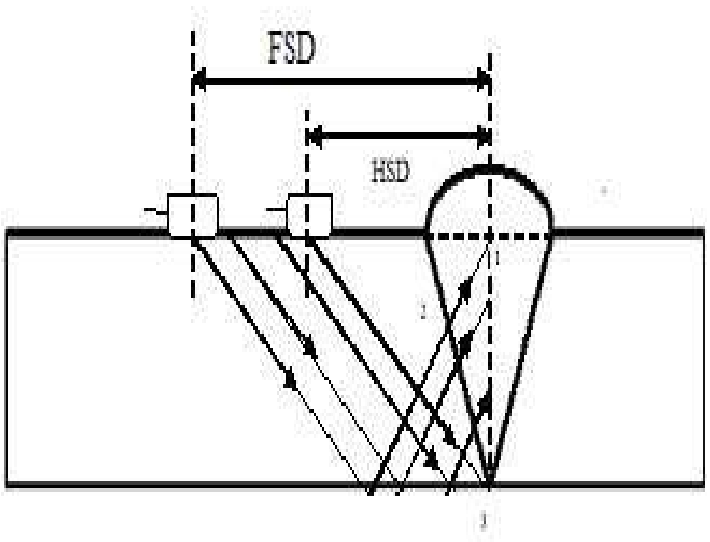
CRT Screen

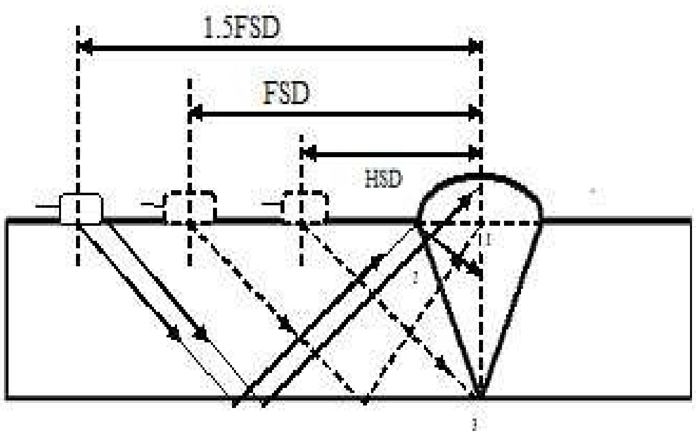
Range calibration with IIW (V1) block

- Place the probe on the IIW (V1) block (with vertical grooves starting at centre of 100mm radius) to obtain a maximum echo amplitude from the curved surface.
- If echo does not comes at their respective position, using control knob, set the echo at exact position.



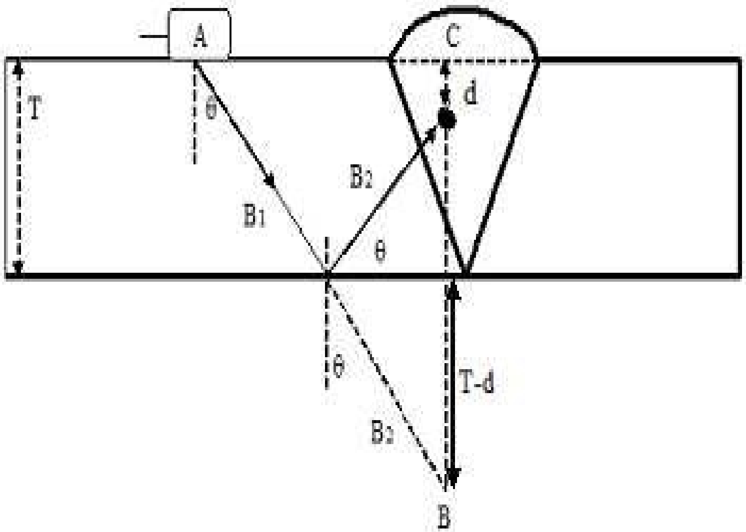
Calculation of the Probe Scanning Positions

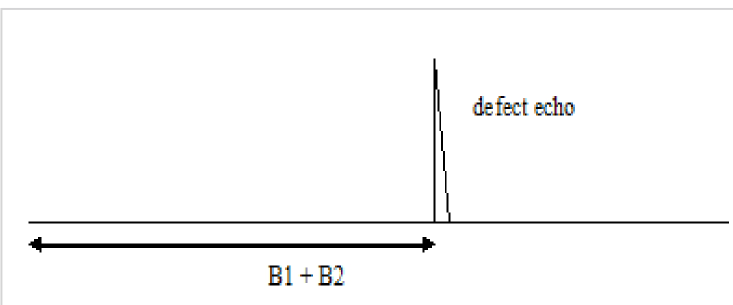




- Calculate half skip and full skip distance.
  HSD = T×tanθ
  FSD = 2T×tanθ
- Now perform scanning between the region FSD and HSD. Move the probe to and fro manner between FSD and HSD.
- Movement of the probe, in the region between FSD and HSD, are capable to inspect the weld area 1-2-3-1as shown in figure.
- For inspection of remaining part of the weld, scan the probe between FSD and 1.5 FSD.
- Perform same scanning procedure for remaining right hand side region of the weld. This gives complete inspection of the weld.

Defect Location





- The location of the defect can be calculated from the knowledge of the beam path length and the probe angle.
- In Δ ABC
  $AB = B_1 + B_2 = B$ (say, can be read from CRT screen).

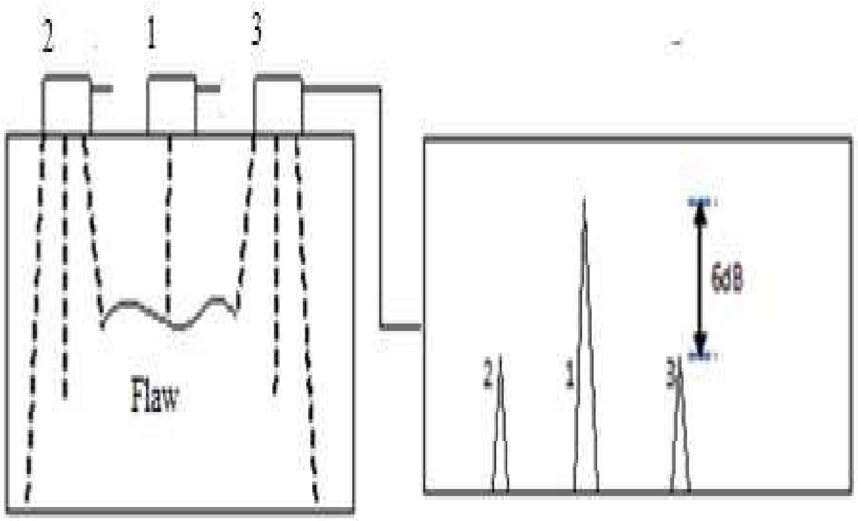
  $BC = T - d + T = 2T - d$

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

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

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

Defect Sizing



- **6dB Drop Method**

  It is based on the basic assumption that when half of the ultrasonic beam is not reflected by a defect, the echo is 50% (6 dB) less than when the entire beam is reflected. It is then assumed that when half of the beam is returned, the transducer centerline is directly over the edge of the defect.

- **20dB Drop Method**

  The 20-dB drop technique is used to size small defects in welds where the intensity falls to 10% (20dB) of the intensity at the center axis of the beam.

Distance Amplitude Correction (DAC) Curve

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

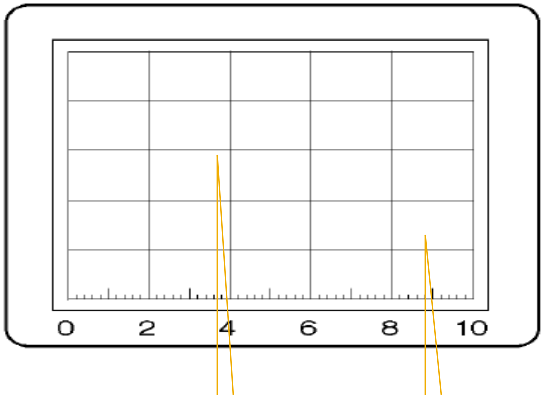
- Usually in angle beam testing, DAC is generated using a specimen with side drilled holes or notches.

- The size of the drilled hole is depends on the acceptance standard of the manufacturer.

- Generally the position of the hole is taken T/4, T/2 and, 3T/4. Where T is the thickness of the reference bock.

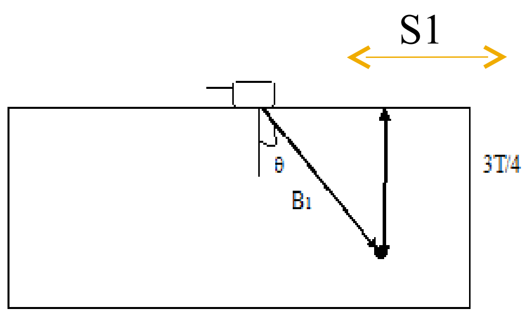
- The location of the holes must be in such a way that at a time, during testing, two holes never come in the path of sound beam.

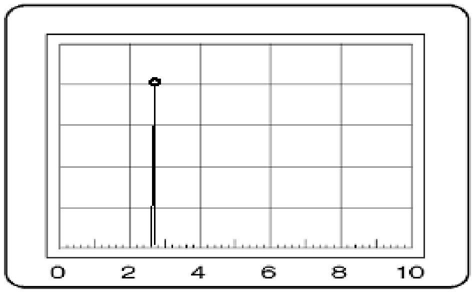
Procedure for Generating DAC..



- **Ex: Make the DAC for 35mm thick block and 60° probe angle.**
- **Step-1**
- Calculate half metal beam path(HMBP) and than calibrate the range.
- HMBP = Tsecθ = 35sec60 = 70mm
- So, **required range = 3×HMBP** = 3×70 = 210mm ≈ 200mm.
- Calibrate the range 0-200mm by using IIW(V2) block.
- 1st echo position = 50/20 = 2 + 10/4 ≈ 2 + 2 = 2 big divisions + 2 small divisions.
- 2nd echo position = 125/20 = 6 + 5/ 4 ≈ 6+1 = 6 big divisions + 1 small division

Procedure for Generating DAC........





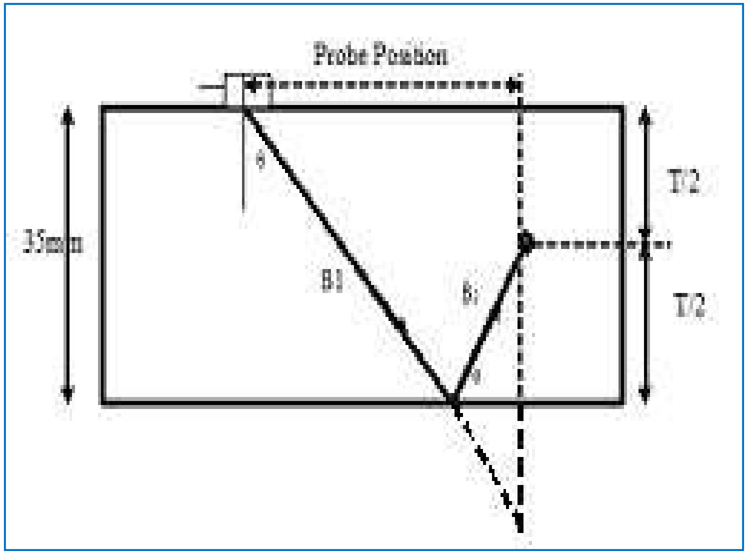
- Step-2. After calibrating the range on CRT screen, take the hole which is located at 3T/4 position.

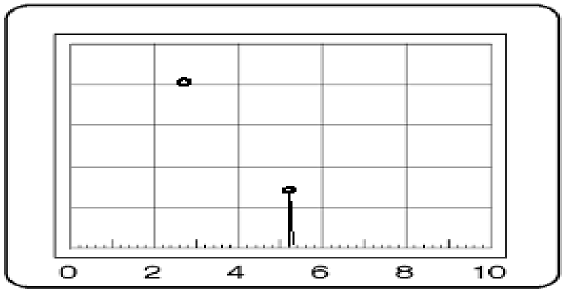
- For 3T/4 hole, calculate probe position (or half skip distance).

- Probe position $S_1 = 3T/4 \tan\theta = 3\times35/4\tan60 \approx 45$ mm

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

Procedure for Generating DAC........





- Step: 3 Now take the hole which is located at T/2 and calculate metal beam path distance (MBPD).

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

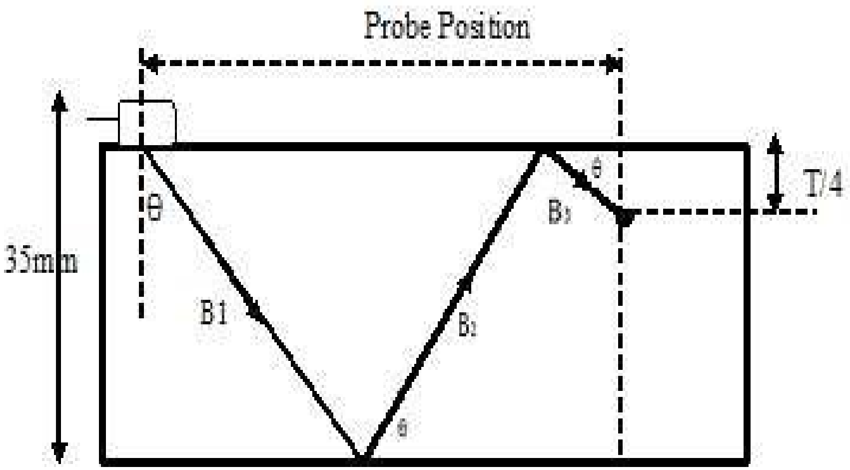
$B_2 = T/2 \times \sec\theta = 35/2 \times \sec 60 = 35\text{mm}$

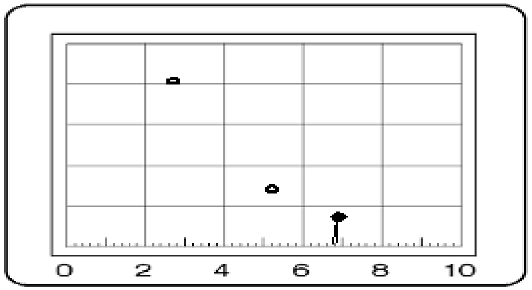
Net MBPD , $B = B1 + B2 = 105\text{mm}$

Probe position, $S_2 = (B_1 + B_2) \times \sec 60 \approx 91\text{mm}$

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

Procedure for Generating DAC........



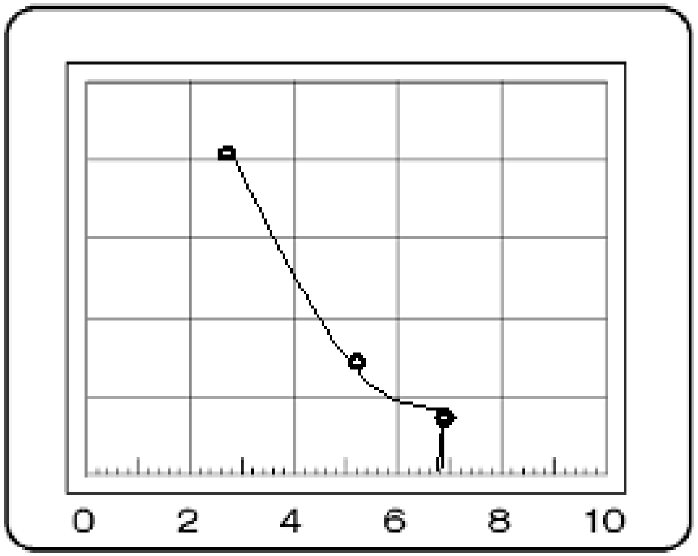


- Step: 4 Now take the hole which is located at T/4 and calculate metal beam path distance.
- Since $B_1 = B_2 = 70mm$ and $B3 = T/4 \times \sec 60 = 15.5$ mm

Net MBPD, $B = B_1 + B_2 + B_3 = 157.5mm$

- Probe position $S3 = B \times \sec 60 \approx 136mm$
- Now put the probe on the desired position and scan for maximum echo amplitude. As soon as you get maximum echo amplitude, mark a sign at the top of the echo on the CRT screen as shown in figure.

Procedure for Generating DAC........



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

Testing of the Weld Joint:

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

Table: 3 Test Parameters

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

➢ Probe angle is selected on the basis of formula 90 –T.

➢ Since weld inspection is carried out with shear waves, so we selected shear velocity of the sound waves.

➢ The inspection of steel component is carried out within the frequency range **1-5 MHz,** so we selected 4MHz frequency probe.

Step: 2- Determination of Probe Index:

Probe index

Step: 3- Determination of Probe Angle:

Step: 4- Calculation and Calibration of the Range:

- Calculate Half Metal Beam Path for given workpiece thickness and probe angle
  HMBP = T×secθ = 16 × sec70 = 46.78 mm

Required Range = 3×HMBP
= 3 × 46.78
≈ 141mm

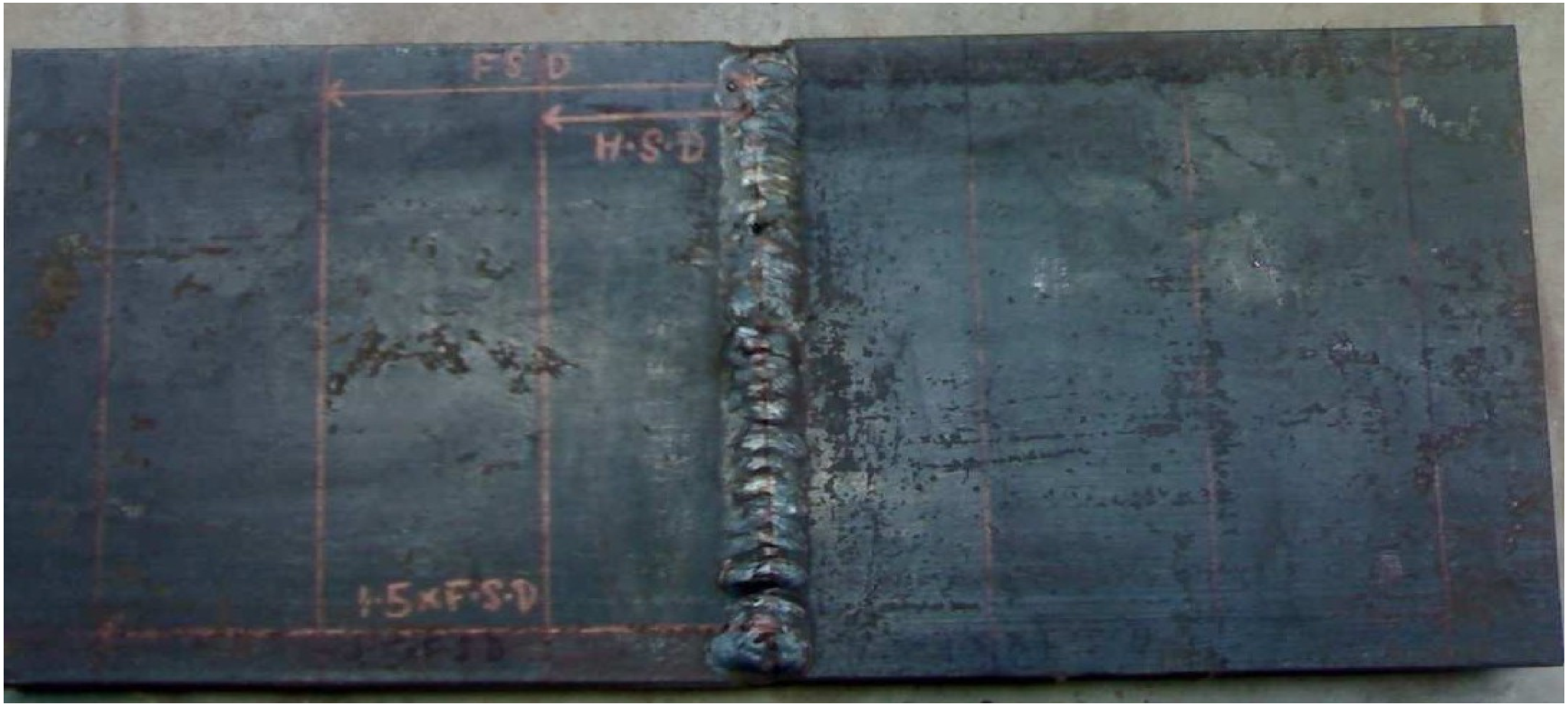
So, we taken range from 0 - 200 mm and calibrated it with the help of (V1) block

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

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

Step: 5- Calculate Probe Scanning Positions:

- HSD = $T \times \tan\theta$ = $16 \times \tan 70$ ≈ 44mm
- FSD = $2T \times \tan\theta$ = $2 \times 16 \times \tan 70$ ≈ 88mm
- 1.5FSD = $3T \times \tan\theta$ = 131.88mm ≈ 132mm



Step: 6 Testing of the Weld Piece:

- Apply the couplant and move the probe to and fro manner between HSD, FSD and 1.5FSD regions.

1st Defect:

From figure we can see a defect echo on screen which appears at 15mm scale division.

The depth of the defect $d = 2T - B \times \cos\theta$ = 14.90 mm.

The surface distance of the defect from the centre of the probe $S = B \times \sin\theta$ = 46.98 mm.

Testing of the Weld Piece……….

Defect Free Weld Zone

Testing of the Weld Piece……….

2nd Defect

For 2nd defect, B = 18 mm scale division.
So the depth is 12mm
Surface distance from the probe centre is 56.38mm.

Testing of the Weld Piece..........

3rd Defect

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

Testing of the Weld Piece……….

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

Result and Discussion

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

- **1st Defect,**
  Depth is14.90mm and distance from the centre of the probe is 46.98mm.

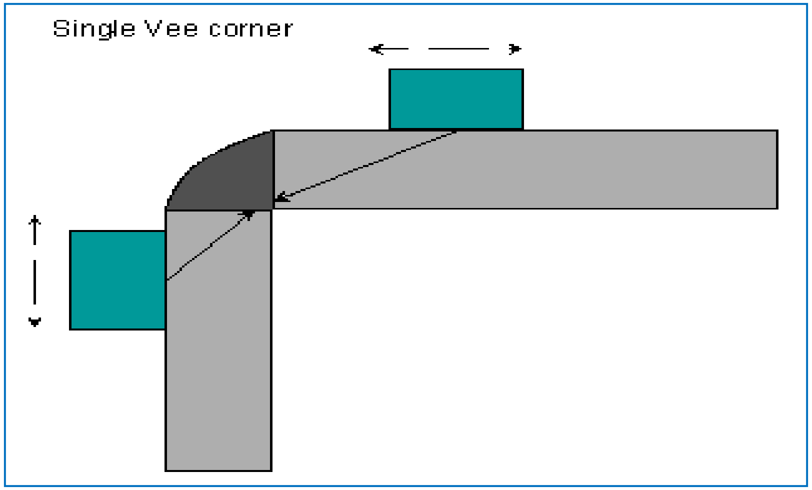
- **2nd Defect**
  Depth is 12.00mm and surface distance from the centre of the probe is 56.38mm.

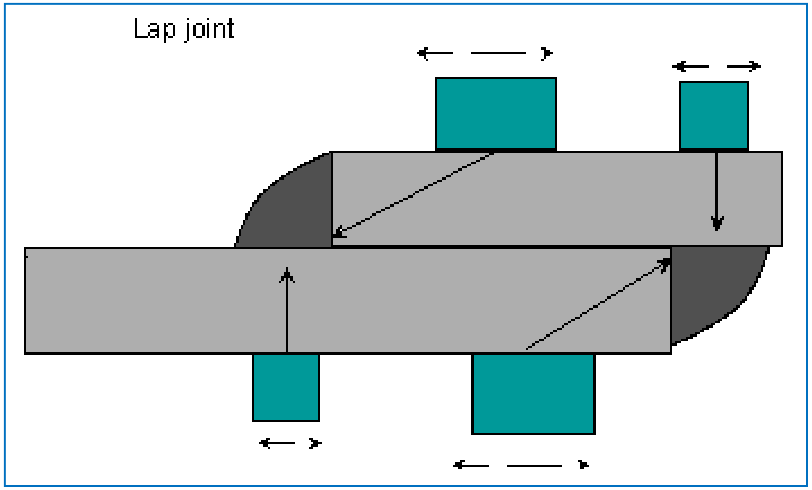
- **3rd Defect**
  Depth is 15.00mm and surface distance from the centre of the probe is 47.00mm.

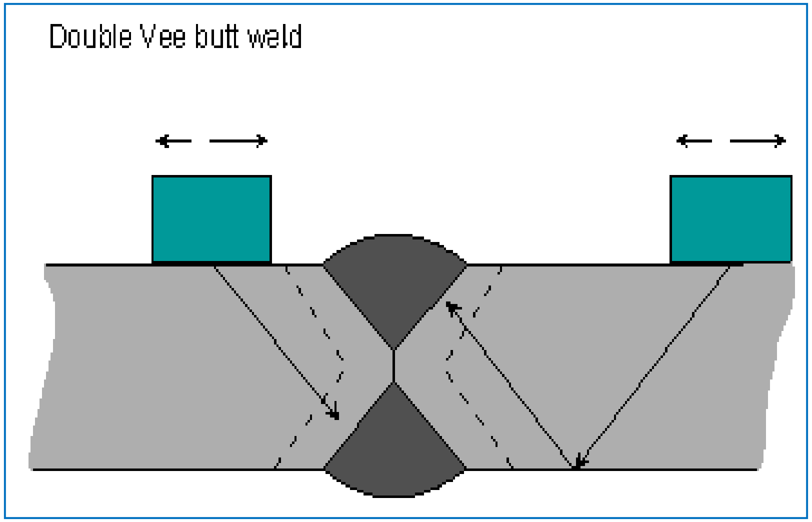
Recommendations:

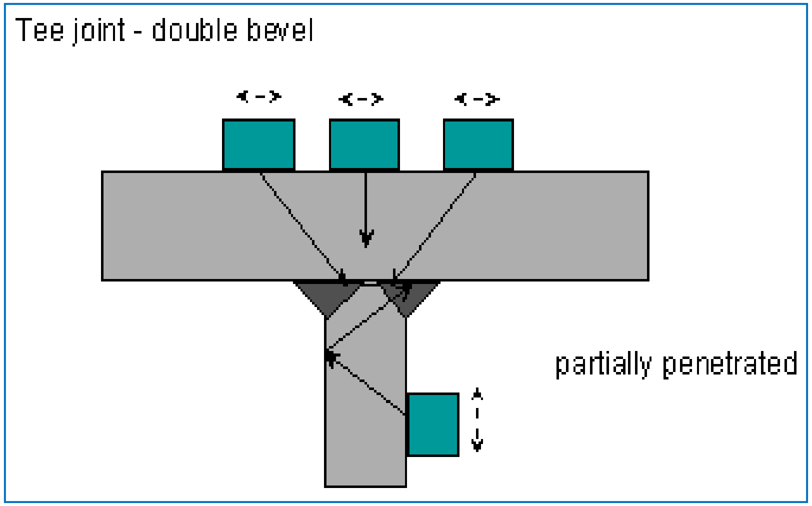
- Perform scanning from both sides of the weld with sufficient overlap to ensure complete coverage and with a swivel motion of the probe.
- Because of high attenuation and scattering of sound beam, steel welds gives very poor signal to noise ratio. So be careful at the time of selecting echo indication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

Ultrasonic Inspection of Other Weld Joints:

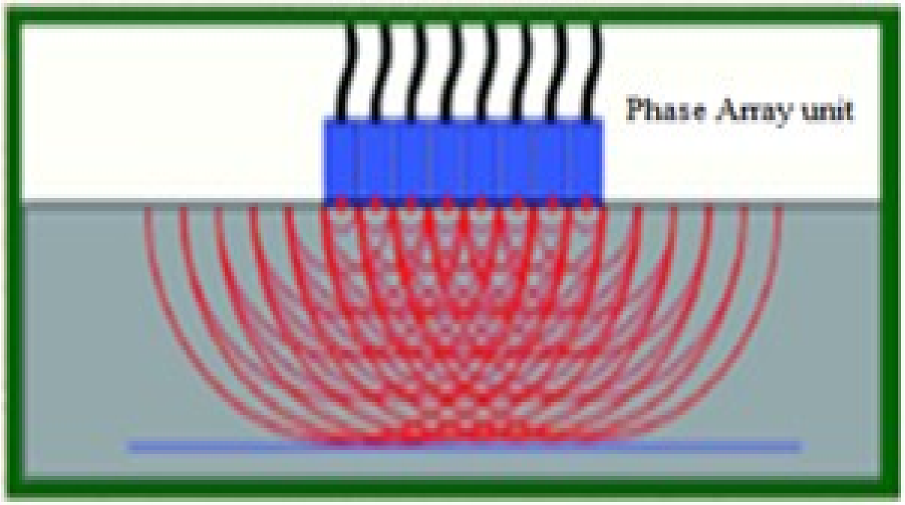








Recent Development in UT

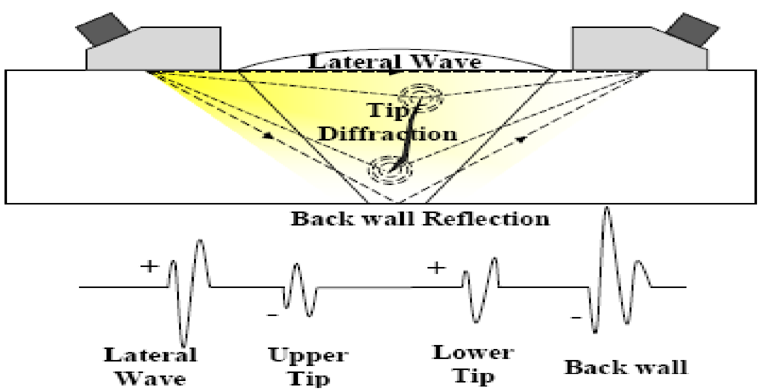


Phase Array Ultrasonic Testing

A phase array probe consists of many small transmitting and receiving ultrasonic elements (piezoelectric elements) that are arranged at a certain distance from each other, each of which can be pulsed separately in a programmed manner. The phased array principle is based on the time-delayed activation of each element.

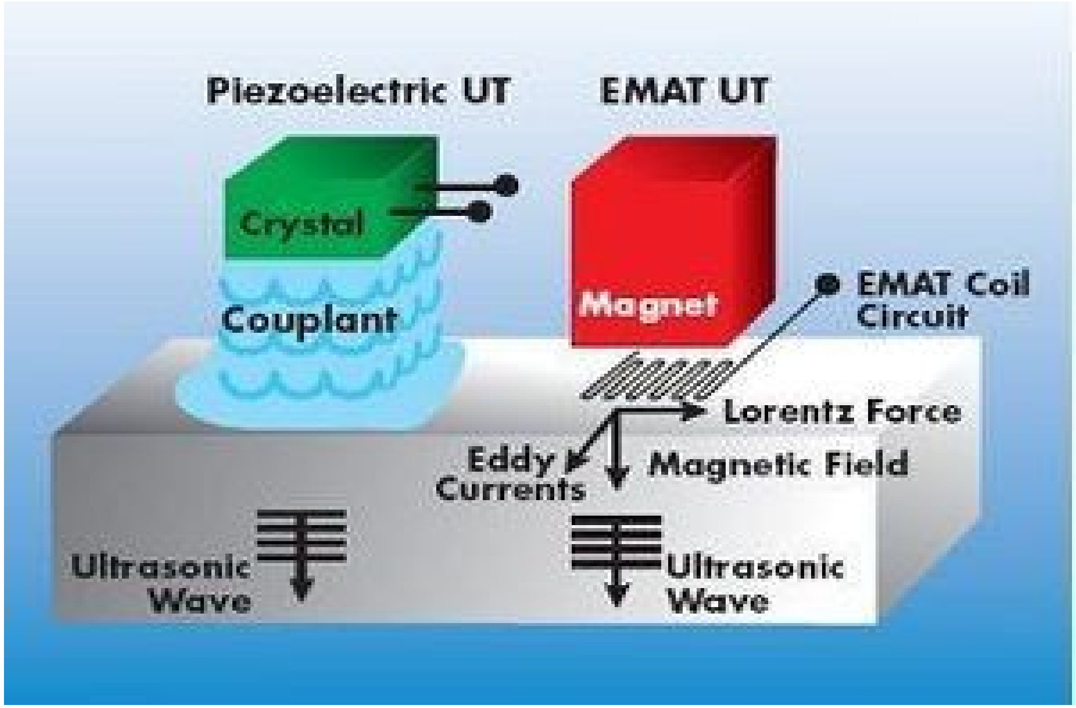
Recent Development in UT………

- **Time of Flight Diffraction (TOFD) Technique:** TOFD is based on measurement of the time of flight of the ultrasonic waves **diffracted** from the tips of the defect. The following signals are observed in TOFD technique:
  - The diffracted signal from the upper tip of the flaw
  - The diffracted signal from the lower tip of the flaw
  - The backwall (inner) surface from the longitudinal wave
  - The backwall (inner) surface from the trailing shear wave component.



Recent Development in UT.........

- **Electromagnetic Acoustic Transducer:** EMATs generate and detect ultrasonic waves via electromagnetic coupling between the EMAT and the metal to be tested. Depending on the orientation of the force, it is possible to generate different types of ultrasonic waves. They operate via the Lorentz force or magnetostriction mechanisms.



Advantages and Disadvantages of UT

- ## Advantages of Ultrasonic Testing

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

- ## Disadvantages of Ultrasonic Testing

- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration and the characterization of flaws.

Applications

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

THANKYOU