Subject : Non – Destructive Testing (Elective 1 - ME 367)

Semester : V

Course : B Tech - Mechanical Engineering

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Department of Mechanical Engineering MACE

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Mentoring to ensure excellence

MISSION

- **To facilitate comprehensive and integrated development of students by providing quality education**
- **To mould disciplined and socially committed engineers capable of assuming professional leadership**

MODULE 1
Visual Inspection

Destructive Testing
Vs
Non Destructive Testing

Destructive testing comprises of various test methods where the specimen is destroyed/ damaged/ broken to determine the physical and mechanical properties.

Non-destructive testing (NDT) involves wide range of techniques for determining the characteristics of materials and to locate the defect without damaging the specimen.

Destructive Testing

- **Advantages**

1. Measurements are direct and reliable
2. Usually quantitative measurements
3. Correlation between test measurements and material properties are direct

Destructive Testing

- **Disadvantages**

1. Damages the specimen
2. Single test may measure only one or few of the properties
3. In-service testing is not possible
4. Qualitative measurements are not possible.

Non Destructive Testing

- **Advantages**

1. Does not damages the specimen
2. 100% testing on actual components is possible
3. In service testing is possible, so break down can be prevented.
4. Repeated checks over a period of time are possible to reduce accidents and safety issues.
5. Test results are rapid

Non Destructive Testing

- **Disadvantages**

1. High initial investment required
2. Skilled and experienced worker is required to conduct the test and to interpret the result.

Scope of NDT

- To provide quality control of a product during manufacturing stage or during fabrication.
- To ensure that an item confirms to required specification.
- To examine a plant, equipment or components during service to ensure that the requirements are met and to prevent breakdown or failure.
- As a diagnostic tool in research and development.

Type of defects

- Inherent defects – Caused during the initial production of the base / raw materials
- Processing defects – Caused during processing of the material or part
- Service defects – Caused during the operating cycle of the material or part

Introduction to Visual Inspection

- Visual inspection is the most basic and most commonly employed NDT method.
- It is applicable to a wide variety of material types and product forms.
- Several characteristics about the part being examined may be determined, which include dimensional conformance, the presence of discontinuities, general fit and wear, and simple cosmetic compliance.
- It can be performed by direct or indirect methods during various stages of manufacturing or after the component has been placed in-service.

Visual Inspection

Most basic and common inspection method.

Visual inspection refers to an NDT method which uses eyes, either aided or non-aided to detect, locate and assess discontinuities or defects that appear on the surface of material under test.

Tools include fiberscope's, borescopes, magnifying glasses and mirrors.

Defects such as corrosion in boiler tube, which cannot be seen with naked eyes can easily be detected and recorded by using such equipment.

Types of Visual Inspection (VI)

1. Direct visual testing
2. Remote/ Indirect visual testing

Direct Visual Testing

- Inspection using naked eye, magnifying lenses, Mirrors etc

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Remote/ Indirect visual testing

- Fiberscope, bore scope, robotic crawlers etc are used

Microscope

- Microscope a combination of lenses used to magnify the image of a small object.
- The object is placed close to the lens to obtain as high magnification as possible.

Bore scope

- Bore scope is an instrument designed to enable an observer to inspect the inside surface of narrow tubes, bores, chambers etc.
- It consists of precision built in illumination system having a complex arrangement of prisms and plain lenses through which light is passed to the observer with maximum efficiency.

Endoscope

- An endoscope is almost similar to bore scope.
- Endoscope has a superior optical system and a high intensity light source.

Fibre optic bore scope (Fibrescope)

- A flexible fibre optic bore scope permits the instrument to access corners and through passages with several directional changes.
- It is designed to provide sharp and clear images of parts and interior surfaces that are normally impossible to inspect.

Fiberscope & Bore scope

Telescope / CCTV

- Telescope is used to obtain magnified images of objects at considerable distance from the observer.
- It is particularly use full for providing visual examination of the surface which is other wise inaccessible.
- A Closed Circuit Television (CCTV) can be also used for inspecting inaccessible areas.

Robotic crawlers

(Eg. For inspecting crude oil pipelines)

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Applications of visual inspection

- Inspection of plant/ systems/ component for any leakage, abnormal operation etc…
- Misalignment of parts in equipments
- Corrosion, erosion, cracks, fractures etc
- Defects in weldments such as surface cracks, lack of penetration, porosities etc

Visual Inspection

Advantages :-

- Cheapest NDT method
- Applicable at all stages of construction or manufacturing
- Do not require extensive training
- Capable of giving instantaneous results

Limitation :-

- Limited to only surface inspection
- Require good lighting
- Require good eyesight

Fundamentals of visual testing

1. Vision

- Human eye is the most valuable NDT tool
- Sensitivity of human eye varies according to varying light sources.
- For maintaining efficiency, a human operator is not allowed to work for more than 2 hours continuously.

Fundamentals of visual testing

2. Lighting

- Proper lighting plays vital role in VI
- Improper lighting results in poor quality images even under high magnification
- Amount of light required depends on type of test, importance of accuracy, glare and operator's visual capability.
- For VI, suitable lighting of about 800-1000 lux is required.
- **Light sources**: Incandescent lamps, fluorescent lamps & high intensity discharge lamps.

Fundamentals of visual testing

3. Material Attributes

- Cleanliness: Test surface should be cleaned properly
- Colour: Colour of surface determines colour of lighting to be used.
- Physical conditions of test surface like texture, shape, size & contour determines the tool & type of lighting to be used.

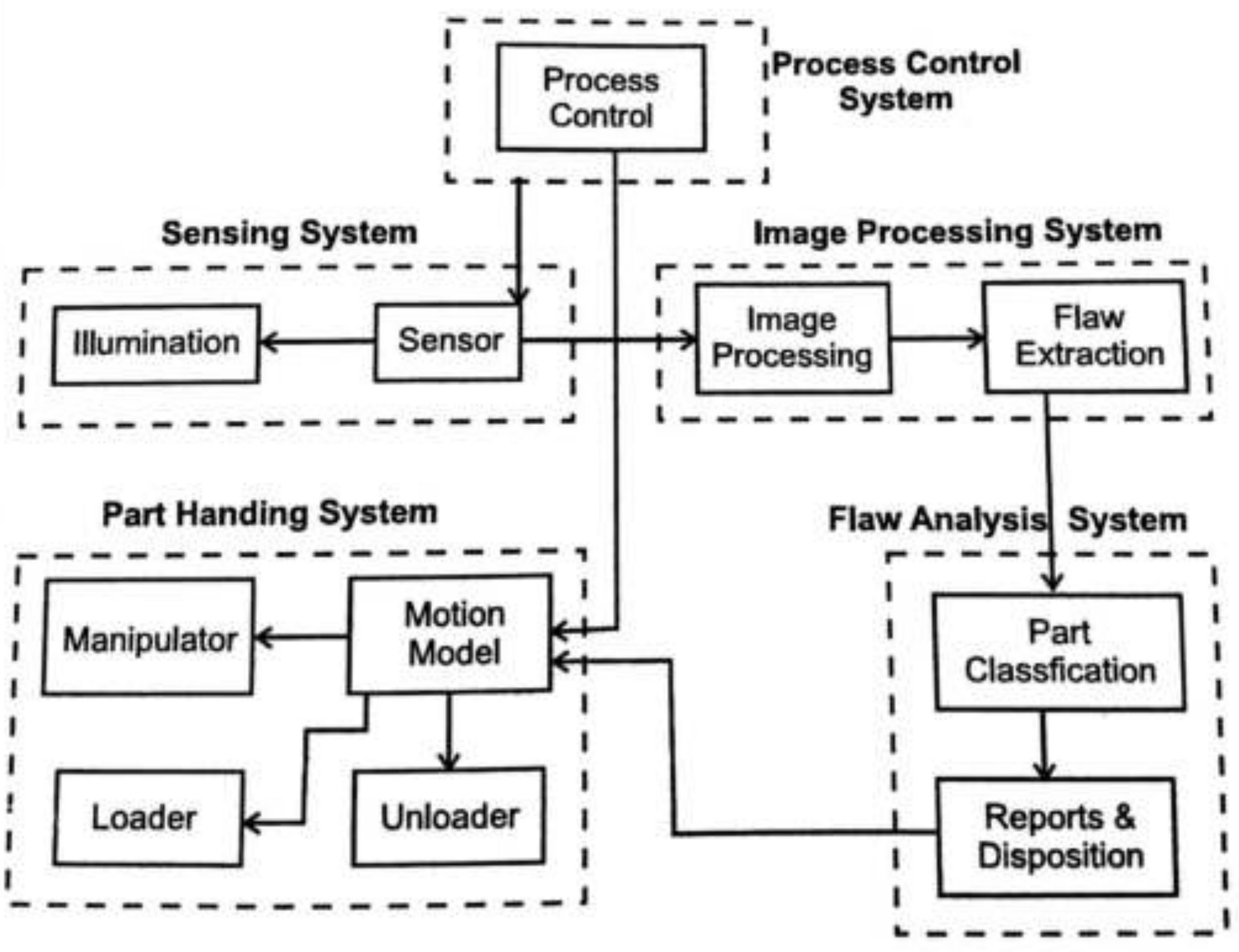
Fundamentals of visual testing

4. Environmental Factors

- **Atmosphere**: Clean & clear atmosphere provides good test results
- **Humidity & temperature** levels of test surface should be considered before finalizing the inspection tool.
- **Safety** of the operator should be considered in risky environments.

  (Eg: Using robotic crawlers instead of human operator for inspecting long crude oil pipelines)

Computer enhanced visual inspection system



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Computer enhanced visual inspection system

1. **Process control system**
- Controls overall inspection process
- Provides commands and signals to control system’s database.
2. **Sensing system**
- Provides adequate illumination

Computer enhanced visual inspection system

3. **Image processing system** captures, processes and detects defects/ flaws in the images.
4. **Flaw analysis system** examines the defects/ flaws on images received from image processing system.
5. **The micro processor/ soft ware** then decides whether the specimen is to be accepted or rejected.

Computer enhanced visual inspection system

Advantages

- The system can be re programmed and can be used to inspect wide range of products
- Can be operated through out the day with out intervals
- Increased speed of inspection compared to human operator
- Consistency of inspection can be maintained.
- 100% inspection of products is possible.

Computer enhanced visual inspection system

Disadvantages

- Skilled labor is required
- Initial investment is high
- Complex programming is required
- Complex lighting system is required
- Real time decision making is impossible.

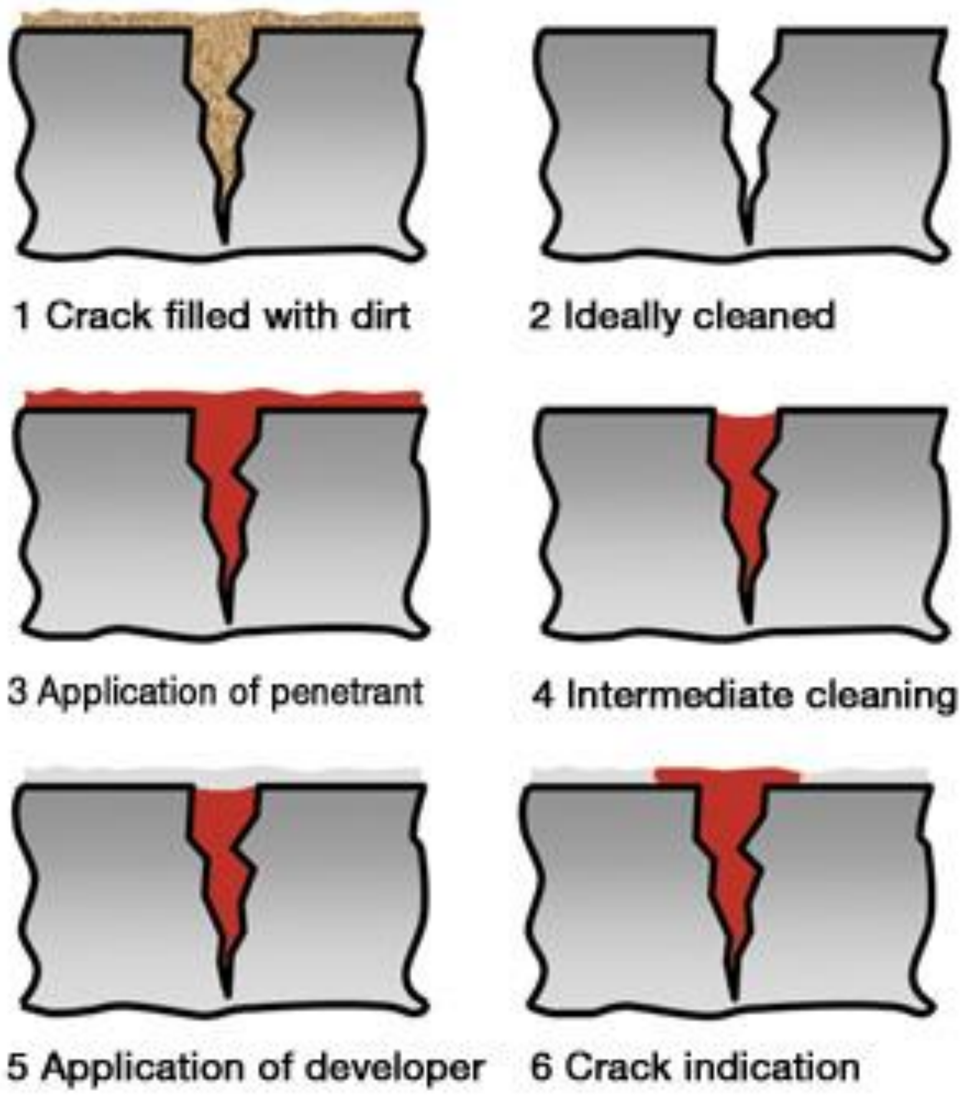
MODULE 2

Liquid Penetrant Inspection

Liquid Penetrant Inspection

Liquid penetrant inspection (LPI) also known as Dye penetrant inspection (DPI) or penetrant testing (PT), is a widely applied low-cost inspection method for locating surface-breaking defects in all non-porous materials like metals, plastics or ceramics.

Liquid Penetrant Inspection



6 Steps in Penetrant flaw detection

- Surface preparation
- Penetrant application
- Removal of excess penetrant
- Application of developer
- Inspection
- Post cleaning and protection

LPI – Working principle

1. Capillary action

- Also known as capillarity or capillary motion or wicking is the ability of a liquid to flow in narrow spaces without the assistance of (or even in opposition to) external forces like gravity.

2. Surface tension

- The cohesive/ attractive force between liquid molecules

Desirable properties of penetrants

1. **Wetting ability** - Good wetting ability improves penetrability and bleed-back characteristics.
2. **Less Volatile -** Highly volatile penetrant chemicals would evaporate too quickly to be practical.
3. **Chemically inert** - Penetrant materials should be inert and non-corrosive in nature.
4. **Viscosity**

- Viscosity relates to the thickness or body of a fluid and is a result of molecular or internal friction.
- Excessive viscosity results in long dwell times, low viscosity leads to reduced dwell times but makes the penetrant prone to over washing.

Desirable properties of penetrants

5. **Solubility** - A penetrant must hold sufficient dye at ambient or high temperature and the dye must not come out of solution if the temperature drops.
6. **Health hazard** - Penetrant used should be non poisonous in nature and should comply with most stringent health and safety requirements.
7. **Availability** – Penetrants should be easily and cheaply available.

Types of Penetrant

Penetrant comes in two basic types

Type 1 - Fluorescent Penetrants: they contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation.

Type 2 - Visible Penetrants: they contain a red dye that provides high contrast against the white developer background.

Fluorescent penetrant systems are <u>more sensitive than visible</u> penetrant systems because the eye is drawn to the glow of the fluorescing indication. However, visible penetrants <u>do not require a darkened area and an ultraviolet light</u> in order to make an inspection.

Types of Penetrant

Classification based on the method used for removing excess penetrant

Method A - Water Washable: penetrants can be removed from the part by rinsing with water alone. These penetrants contain an emulsifying agent (detergent) that makes it possible to wash the penetrant from the part surface with water alone. Water washable penetrants are sometimes referred to as self-emulsifying systems.

Method B - Post-Emulsifiable, Lipophilic: the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible.

Method C - Solvent Removable: they require the use of a solvent to remove the penetrant from the part.

Method D - Post-Emulsifiable, Hydrophilic: they use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash.

Types of Penetrant

Classification based on the strength or detectability of penetrant

Level ½ - Ultra Low Sensitivity

Level 1 - Low Sensitivity

Level 2 - Medium Sensitivity

Level 3 - High Sensitivity

Level 4 - Ultra-High Sensitivity

The procedure for classifying penetrants into one of the five sensitivity levels uses specimens with small surface fatigue cracks. The brightness of the indication produced is measured using a photometer.

Desirable properties of developer

- The material must be absorptive, to perform blotting action.
- For colour contrast penetrants it must mask out background contours and colours
- It must be easily and evenly applicable
- It should be easily and cheaply available.

Desirable properties of developer

- There must be no fluorescing of the developer when used with fluorescent penetrant
- The penetrant bleeding from a discontinuity/ crack must easily wet the developer
- Developer must be of a highly contrasting colour compared to that of penetrant. It seems that the best colour of developer is white.
- It should be removed easily after the test is completed
- It must be non-toxic, non-corrosive and non-irritant.

Types of developers

- Form A - Dry Powder
- Form B - Water Soluble (Powder developer soluble in water)
- Form C - Water Suspendable (Powder developer insoluble in water)
- Form D – Non aqueous Type 1 Fluorescent (Solvent Based)
- Form E – Non aqueous Type 2 Visible Dye (Solvent Based)
- Form F - Special Applications

LPI Kits


Fault-Finder
GROUP 1A
CLEANER
1011
Fault-Finder
GROUP 1A
PENETRANT
1012
Fault-Finder
GROUP 1A
DEVELOPER
1013

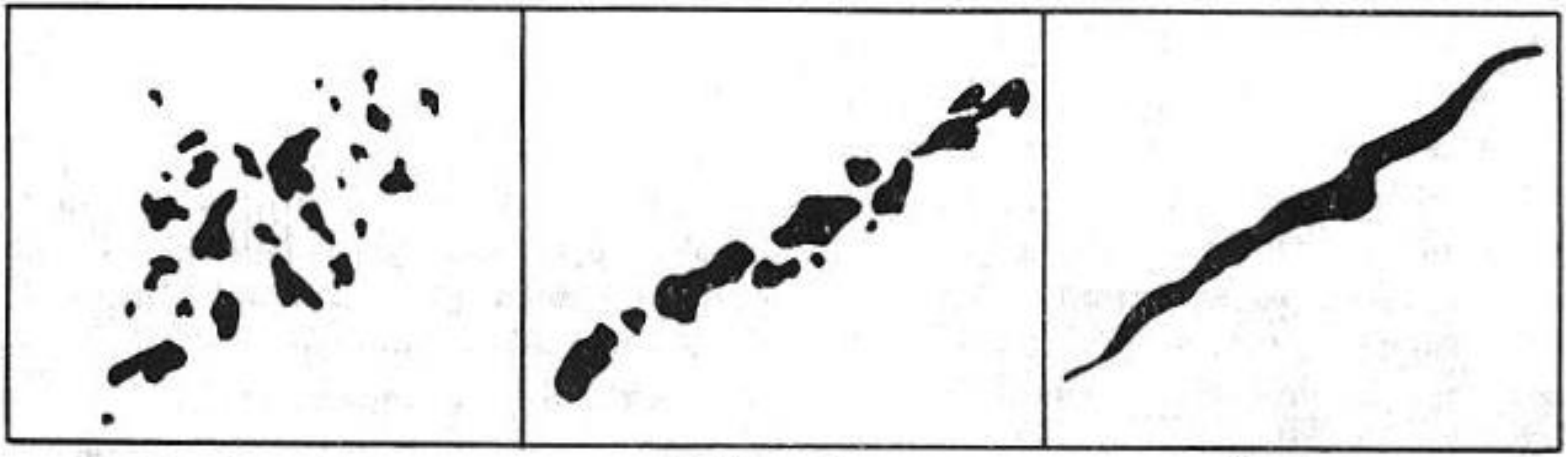
Advantages of LPI

- The method has high sensitivity even to small surface discontinuities.
- Materials including metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials can be inspected.
- Large areas and large volumes of parts/materials can be inspected rapidly and at comparatively low cost.
- Parts with complex geometric shapes are routinely inspected.
- Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
- Aerosol spray cans make penetrant materials very portable.
- Penetrant materials and associated equipments are relatively inexpensive.

Disadvantages of LPI

- Only surface breaking defects can be detected.
- Only materials with a relatively nonporous surface can be inspected.
- Pre cleaning is critical since contaminants can mask defects.
- Metal smearing from machining, grinding, and grit or vapor blasting must be removed prior to LPI.
- The inspector must have direct access to the surface being inspected.
- Surface finish and roughness can affect inspection sensitivity.
- Multiple process operations must be performed and controlled.
- Post cleaning of acceptable parts or materials is required.
- Chemical handling and proper disposal is required

Interpretation of LPI results



Pits of porosity

Tight crack or partially welded lap

Crack or similar opening

Interpretation of LPI results

S.No.	Nature of Defect	Visible Penetrant	Fluorescent Penetrant
1.	Cracks	Thin red lines-depth indicated by the degree of spread	Thin, greenish-yellow lines.
2.	Porosity	Series of red spots spread over the surface	Series of greenish yellow spots.
3.	Very tight crack	Series of very small red dots in continuous formation	Series of very small, greenish-yellow dots.
4.	Shrinkage	Pale red blotches	Pale greenish-yellow blotches.

False indication during LPI

1. Poor washing/ cleaning of excess penetrant

- If excess penetrant is not removed completely during washing/ cleaning/ rinsing after the dwell time, the un removed penetrant will become visible when the developer is applied.

2. Over washing of penetrant

- Over washing of the penetrant will remove the penetrant from the cracks and will not give any indication of the crack when the developer is applied.

False indication during LPI

3. Press fit or assembled parts

- During LPI of press fit or assembled parts penetrants will show an indication at the fit line.

Safety precautions required in LPI

1. Penetrants and developers should not be heated or exposed to open flame.
2. Flammable penetrants and developers should be stored safely in small quantities.
3. Adequate ventilation should be provided in inspection room.
4. Gloves and proper eye protection gears should be used to prevent health hazards.
5. Prolonged exposure to UV light will affect the vision of the worker.

Applications of LPI

- LPI can be effectively used to detect surface discontinuities such as cracks, porosity, seams, cold shuts, lamination and poor weld joints on non porous metallic or non metallic, ferrous or non ferrous materials.

Applications of LPI

1. **Aerospace:** Uses LPI to ensure quality during production and for regular maintenance and safety checks.

- Turbine blades, rotor discs, forged components, weld joints…

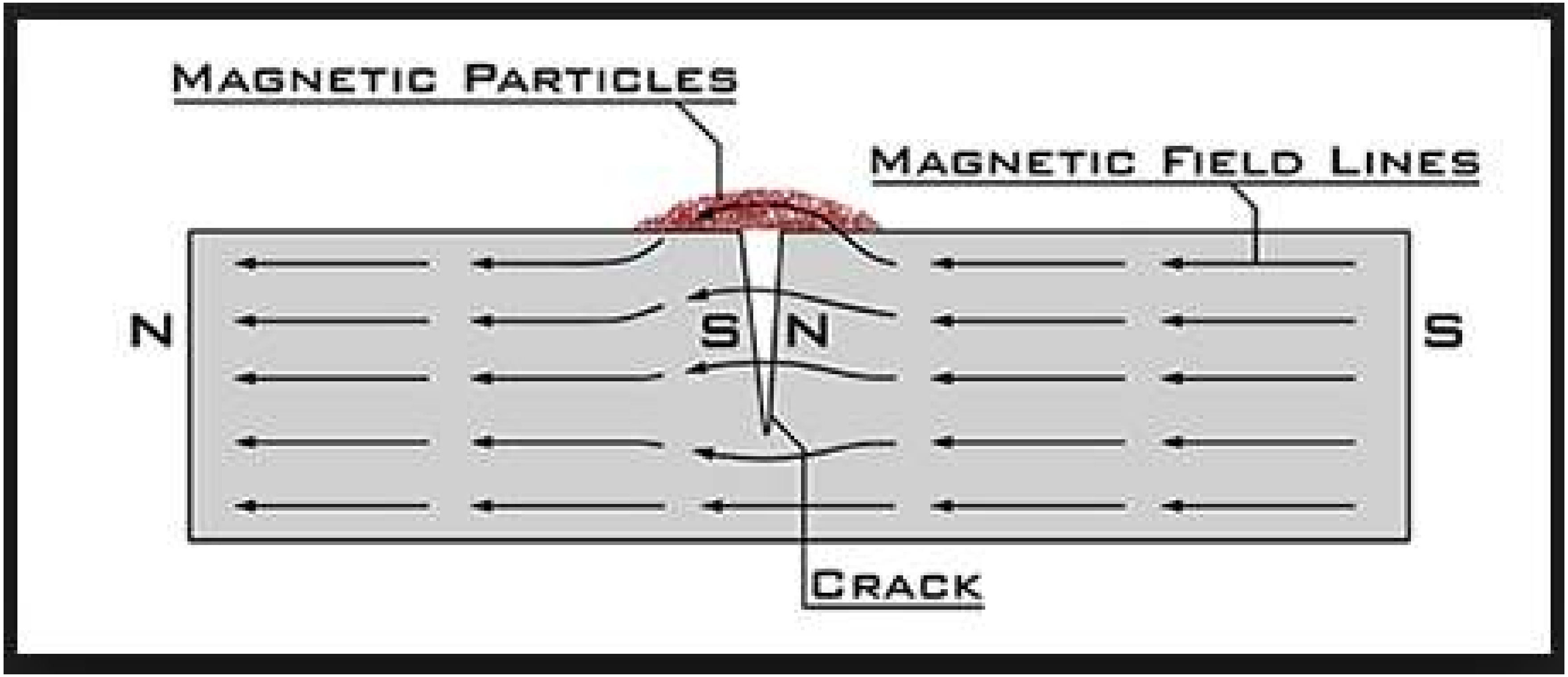
2. **Automobile:** Aluminium engine castings, piston, cylinder head…

Applications of LPI

3. **Railway:** LPI is used to detect fatigue cracking during regular in service safety checks of the bogie frames.
4. **Tools & Dies:** Drilling equipments, tools and dies are inspected by using LPI.
5. **Reactors and tanks:** Tanks, vessels, pumps, and reactors are inspected by using LPI.

MODULE 3
Magnetic Particle Inspection

Magnetic Particle Inspection



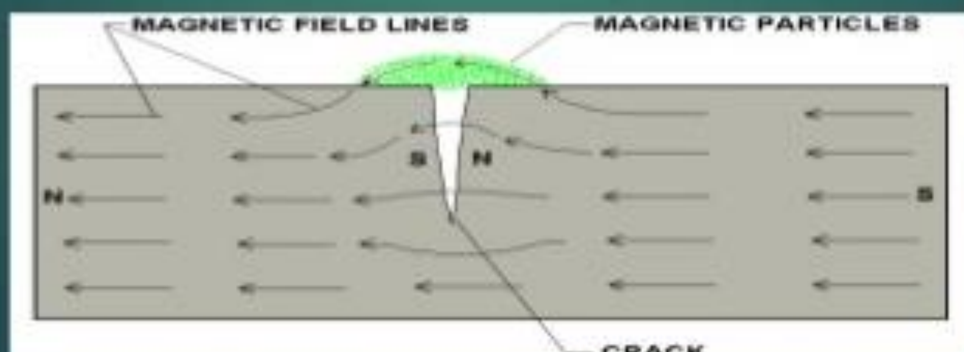
MPI

- **Magnetic particle Inspection** (**MPI**) is a non-destructive testing (NDT) method for detecting surface and slightly subsurface discontinuities in ferromagnetic materials such as iron, nickel, cobalt, and some of their alloys. The process introduces a **magnetic** field into the part.

MPI

working principle

- First step is to magnetize the component which is under inspection
- Secondly iron particles in dry or wet suspended form applied to surface of magnetize part
- The magnetic field is spread out when it encounters with small air gap that is created by the crack making magnetic flux leakage
- Iron particle are attracted and cluster at flux leakage field making a visible crack indication



Basic physics of magnetism

1. Polarity
2. Magnetic force
3. Magnetic field
4. Permeability
5. Flux density
6. Magnetizing force
7. Cohesive force
8. Retentivity
9. Residual magnetism

Basic physics of magnetism

1. Polarity:

- In magnetism, polarity refers to the orientation of north and south poles in space
- Example: The end of a freely suspended magnetized pole pointing towards north is called north pole and other end is called south pole.

Basic physics of magnetism

2. Magnetic force:

- Magnetic force is a force of attraction or repulsion that one body has upon other.
- Example: Opposite poles attracts each other while similar poles repels each other.

Basic physics of magnetism

3. Magnetic field:

- Magnetic field is the area around a magnet in which the magnetic forces are observable.

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Basic physics of magnetism

4. Permeability (μ):

- Permeability is the ease with which a material can be magnetized.
- Materials which gets magnetized under low magnetizing forces are said to have high permeability.

Basic physics of magnetism

5. Flux density:

- Flux density is defined as the number of lines of magnetic force per unit area.
- Flux density is measured in Gauss (B)

Basic physics of magnetism

6. Magnetizing force (H):

- It is the force which tends to set up magnetic flux in a material.

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Basic physics of magnetism

7. Cohesive force:

- Cohesive force is the measure of ability of a ferromagnetic material to withstand an external magnetic field without becoming demagnetized.

Basic physics of magnetism

8. Retentivity:

- The ability of a coil to retain some of its magnetism within the core after the magnetization process has stopped is known as retentivity.

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Basic physics of magnetism

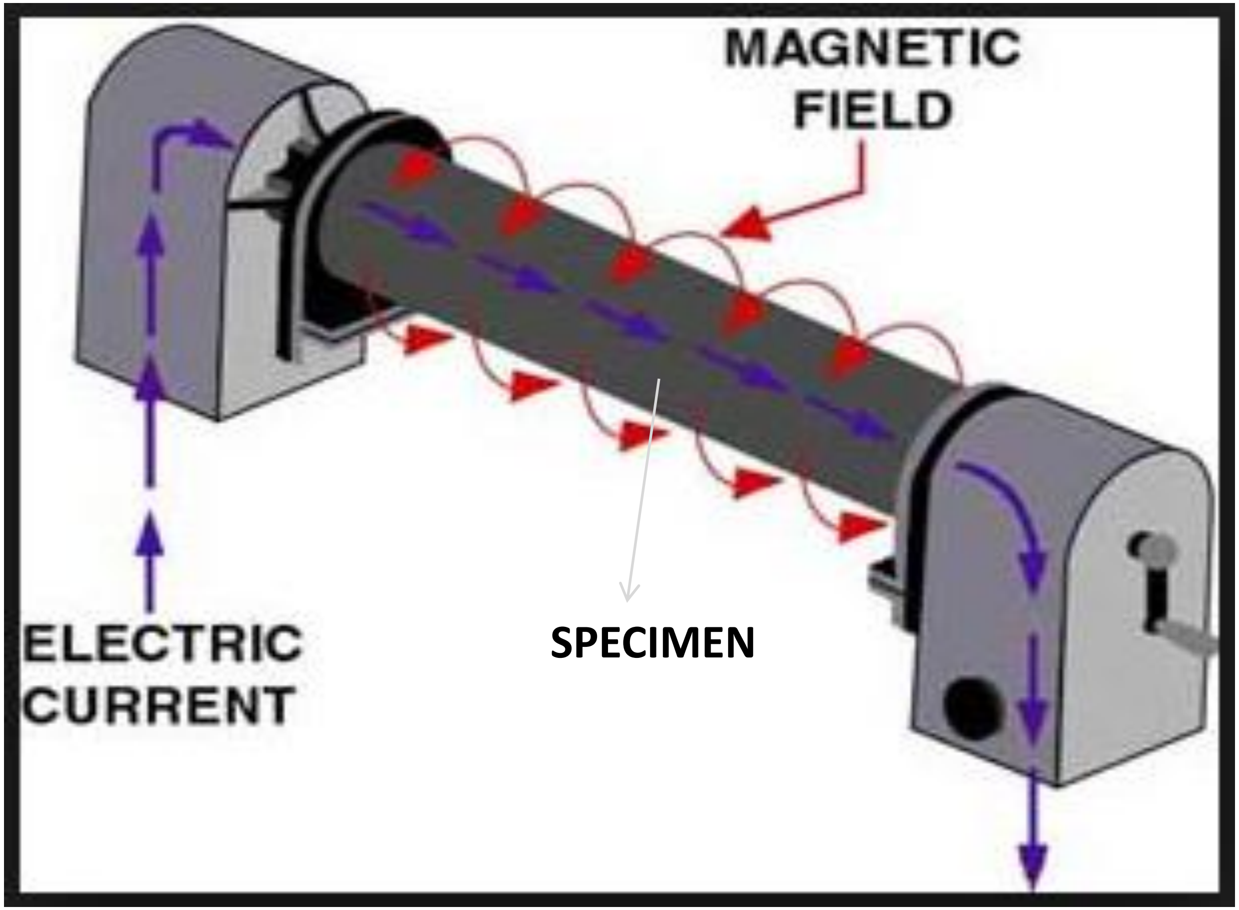
9. Residual magnetism:

- Residual magnetism is defined as the amount of magnetism left behind after removing the external magnetic field from the circuit.

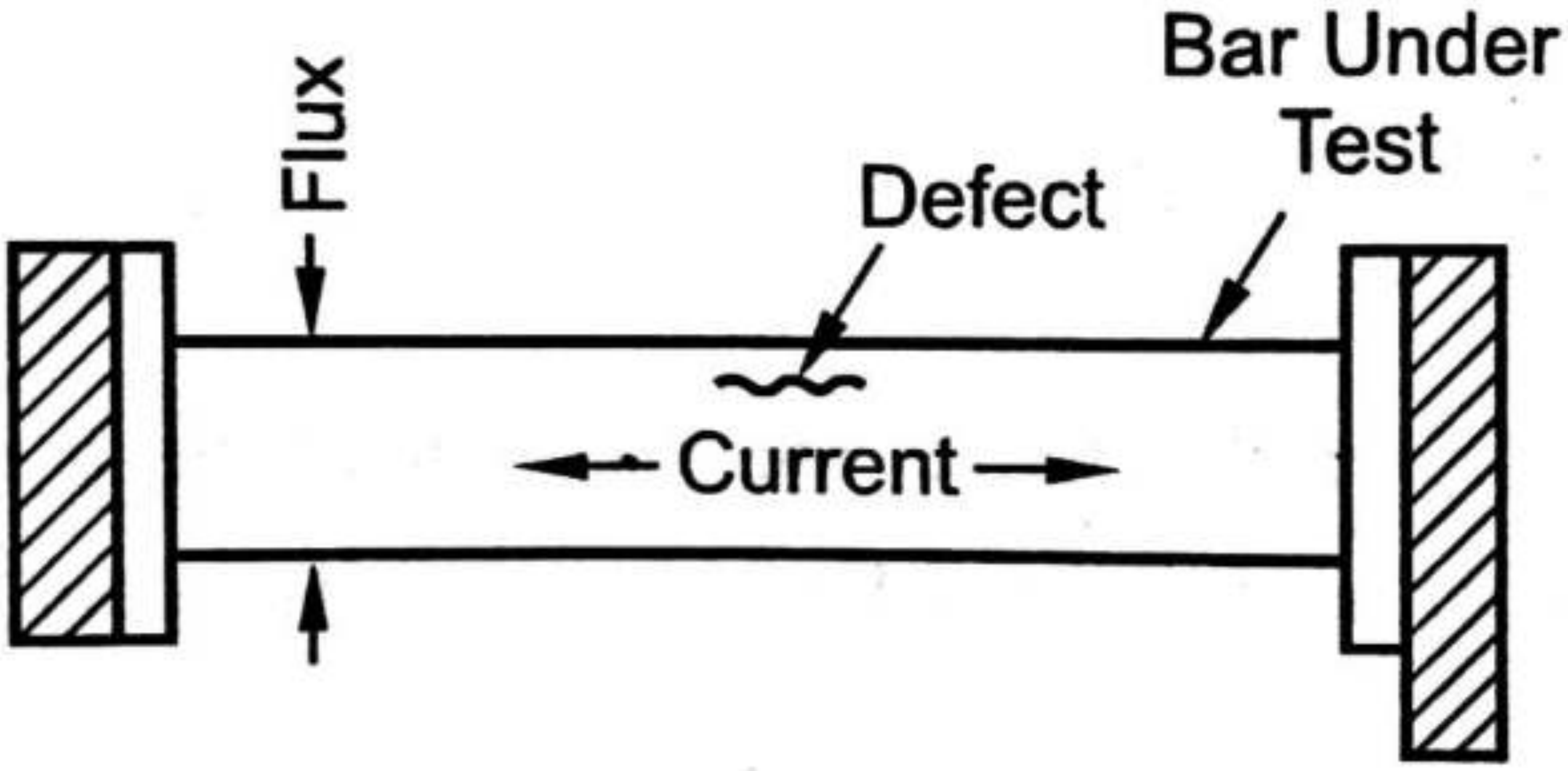
Methods of Magnetization

1. Magnetic flow
2. Current flow
3. Induced current flow
4. Electromagnetic induction

Magnetization techniques
1. Head shot technique



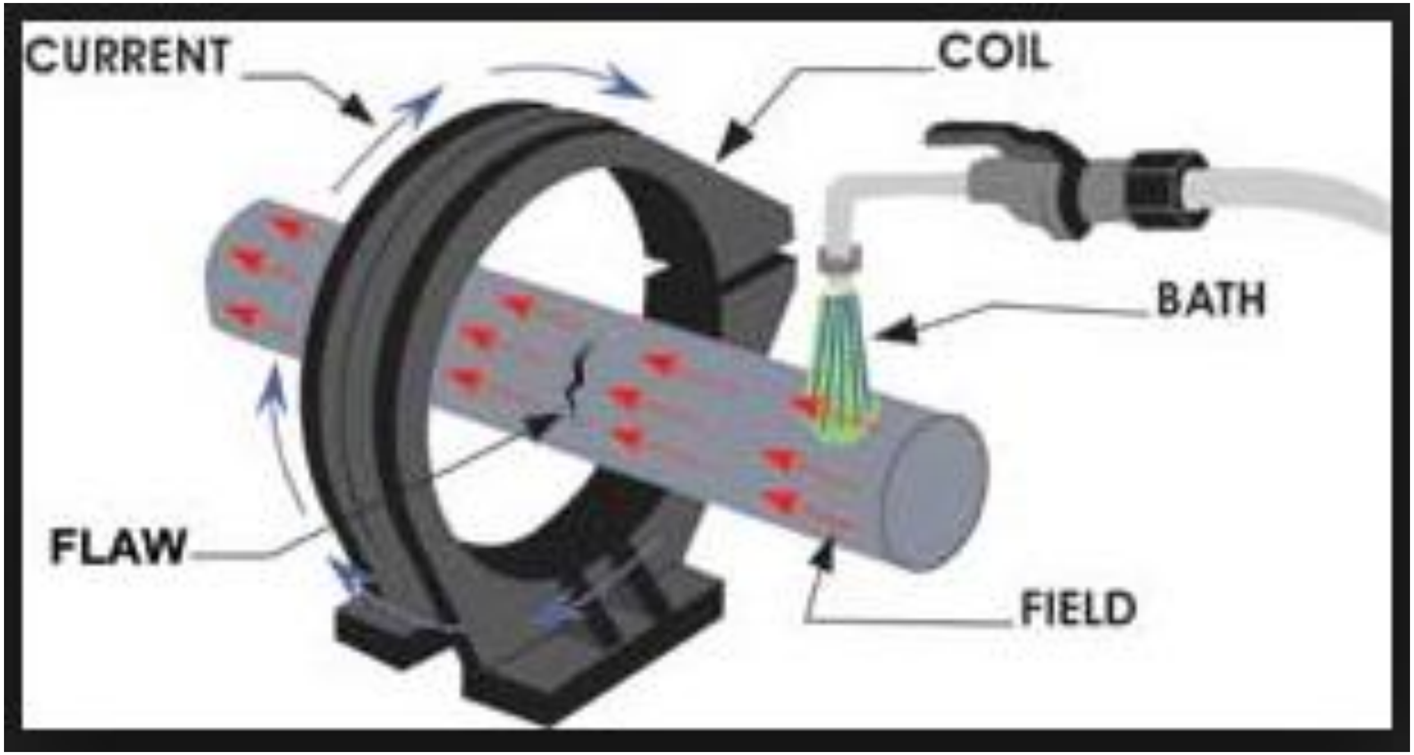
Magnetization techniques
1. Head shot technique



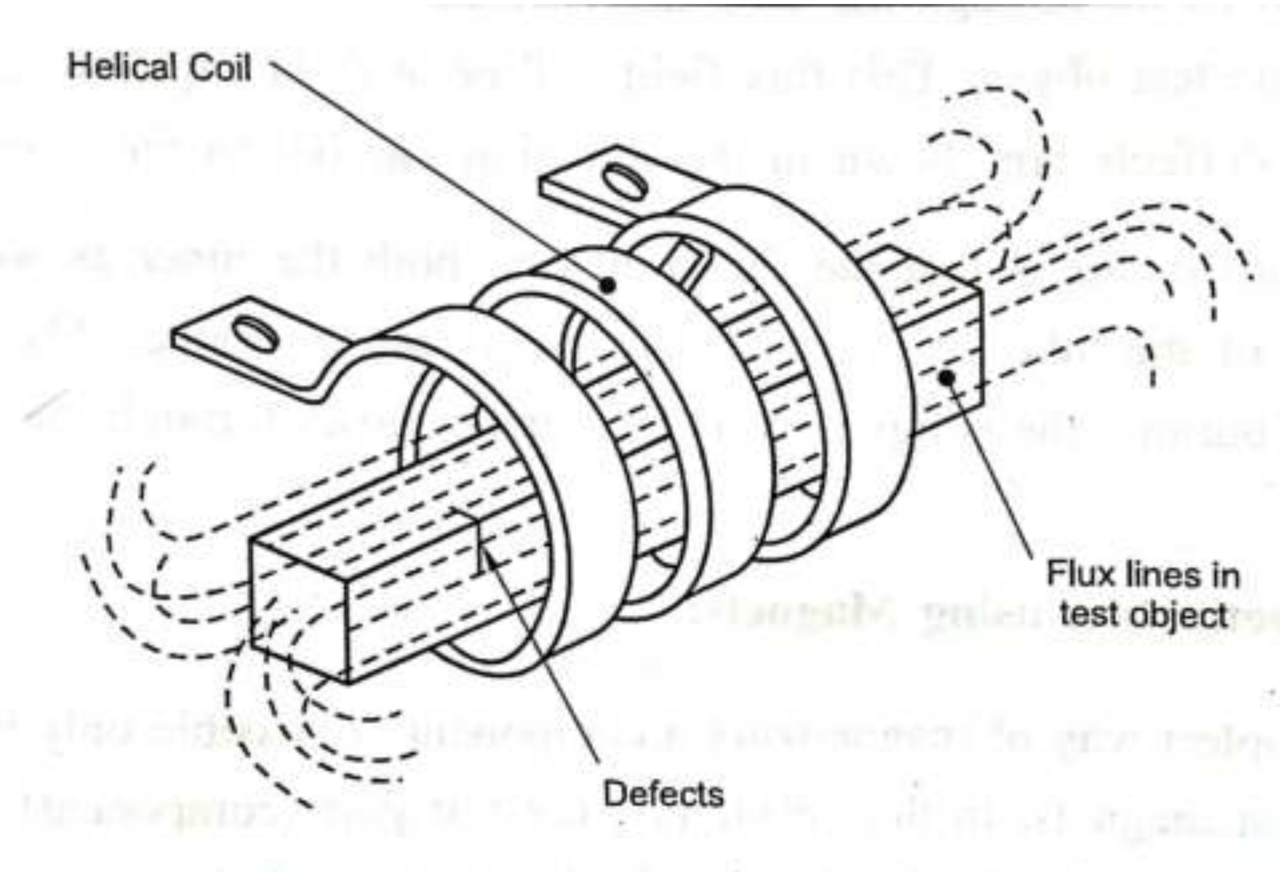
Head shot technique

- Head shot technique produces circular magnetization by passing electric current through the specimen.
- In this method , a round bar is held between heads of a horizontal unit.
- As the current flows from one end to other end of the bar, the magnetic lines of force gets circulated around the bar.
- This circulation of magnetic flux around the bar is known as circular magnetism.

Magnetization techniques
2. Coil shot technique



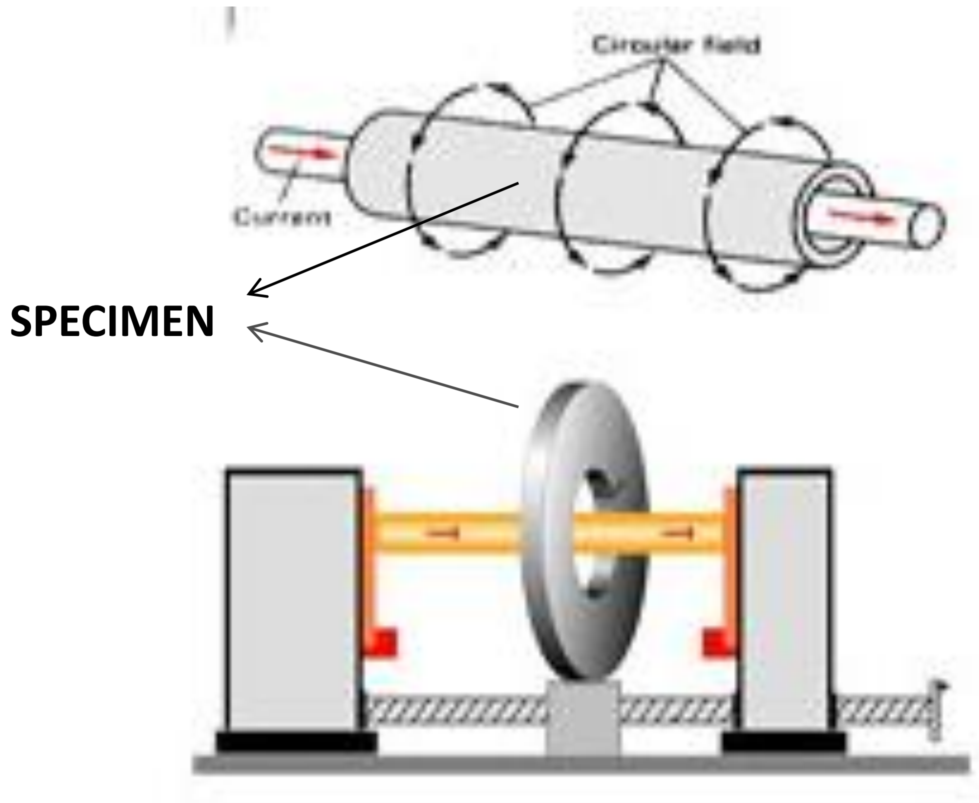
Magnetization techniques
2. Coil shot technique



Coil shot technique

- In this method, the specimen is placed longitudinally within a current carrying coil.
- As current flows through the coil, flux will be generated in the component, creating magnetic poles at its ends.
- This method of producing magnetic field along the longitudinal direction of the component is known as longitudinal magnetism.

Magnetization techniques
3. Central conductor technique

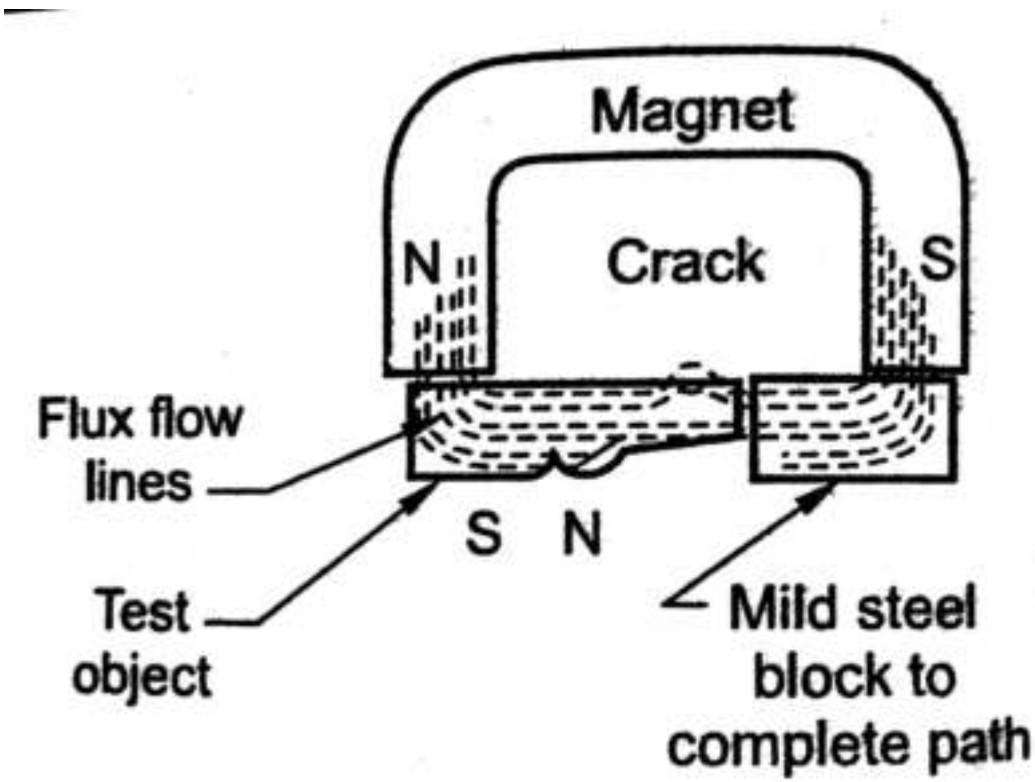


Central conductor technique

- The threaded bar, which is placed inside the specimen is made of good conductor of electricity (Copper or Aluminium)
- As current flows through the bar, the resultant flux field will be generated in the surrounding test specimen.
- Flux lines will be generated in the direction perpendicular to current flow.

Magnetization techniques

4. Magnetization using magnets



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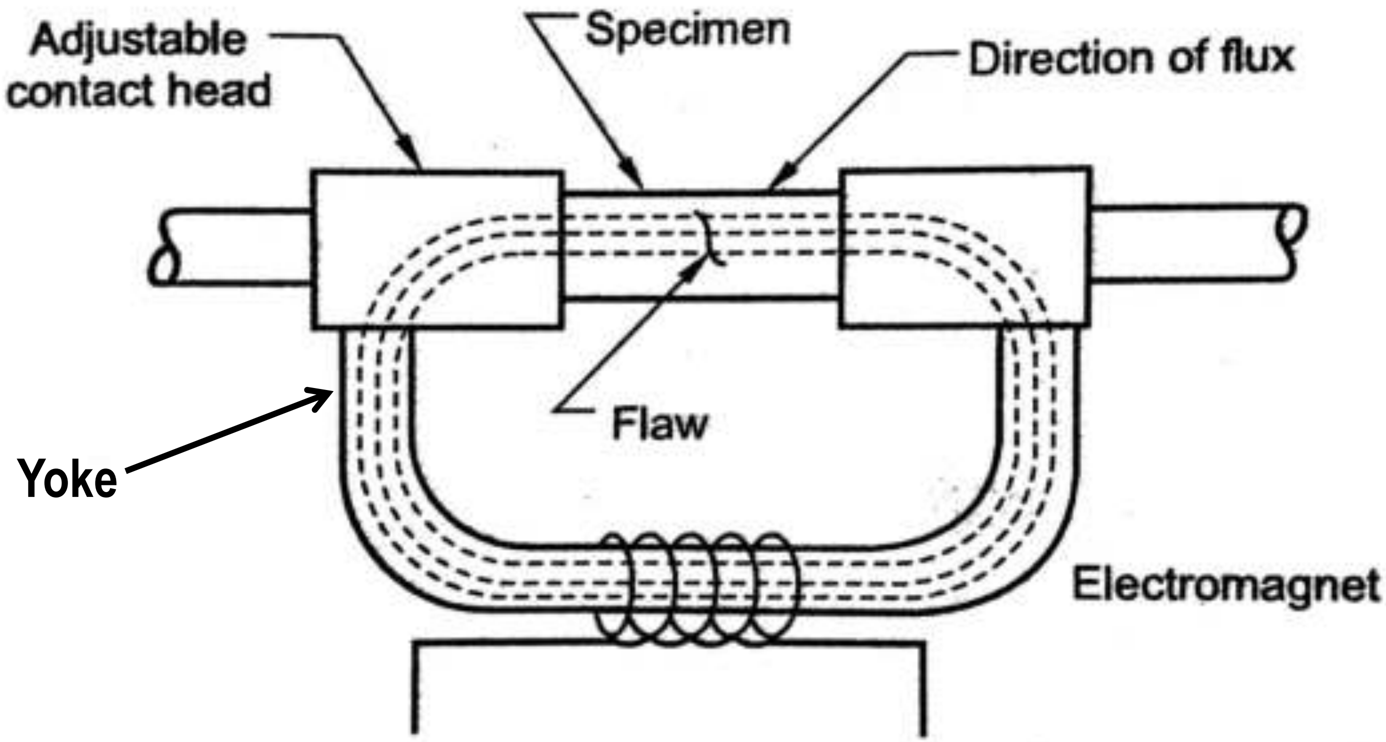
Magnetization using magnets

- In this technique, the specimen to be inspected becomes a part of the magnetic circuit.
- The flux intensity can be varied by using strong or weak magnet or by introducing a gap in the flux path with a thin piece of non magnetic material.

Magnetization techniques
5. Magnetization using yoke



Magnetization using yoke

- Using this method, components of varying cross section can be easily magnetized.
- DC current is varied to provide a wide range of induced flux density.

Direct method of magnetization

- Also known as current flow method
- Current flows through the specimen, thereby completing the electric circuit.
- Magnetic field formed is at right angles to the direction of current flow.
- Eg: Head shot method
- **Advantage**: Easy to use, simple…
- **Limitation**: Melting of specimen occurs when high current is passing through small contact area.

Indirect method of magnetization

- Also known as magnetic flow method.
- In this method, specimen becomes a part of the magnetic circuit, thus bridging the part between the poles of a permanent magnet.
- **Advantages:**
- Melting of critical components can be prevented, as direct current is not passing through the specimen.
- Permanent or electro magnets can be effectively used for inspection at closed or remote areas.

Continuous testing of MPI

- Continuous testing means that the magnetic particles are applied while the current is still flowing through the specimen.

Continuous testing of MPI

- Classifications

1. **Dry continuous** – The term dry means that dry magnetic particles are applied in fine particle form.
2. **Wet continuous** – The term wet means that the magnetic particles applied are suspended in a liquid carrier. (Eg. – Kerosene, Petroleum distillates, Water + additives)

Dry Continuous

- **Advantages**

1. Easy to apply and clean
2. Less hazardous

- **Disadvantages**

1. Mobility of particle is less
2. Curved or complex shapes cannot be inspected

Wet Continuous

- **Advantages**

1. Mobility of particle is more compared to dry type
2. Curved or complex shapes can be easily inspected

- **Disadvantages**

1. Post cleaning is difficult
2. Hazardous & corrosive in nature

Residual Technique of MPI

- In residual technique, magnetic particles are applied after current supply is ceased.
- The material should have sufficiently high retentivity to retain magnetization force for performing the test.

Residual Technique of MPI

- **Dry residual technique**: In this method, dry magnetic particles are used after the magnetization force has ceased.
- **Wet residual technique**: In this method, magnetic particle suspension is used after the magnetization force has ceased.

System Sensitivity

- Sensitivity of MPI system can be increased by implementing following steps:

1. AC magnetization is most effective for detecting surface defects
2. DC magnetization is effective for subsurface defects
3. Half wave DC gives improved penetration
4. Half wave DC dry method gives maximum penetration.

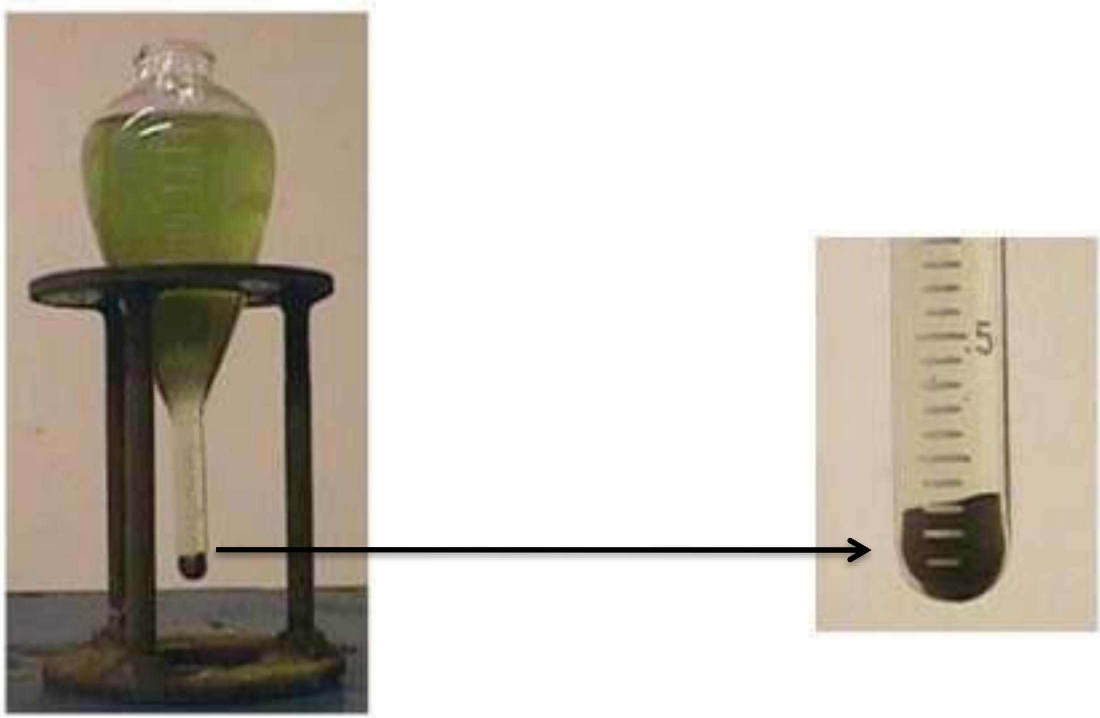
Checking devices in MPI

- To maintain consistency and high levels of accuracy, following checking devices are commonly used

1. Settling test
2. Ketos ring
3. Field indicator
4. Suspension contmination
5. Ammeter accuracy

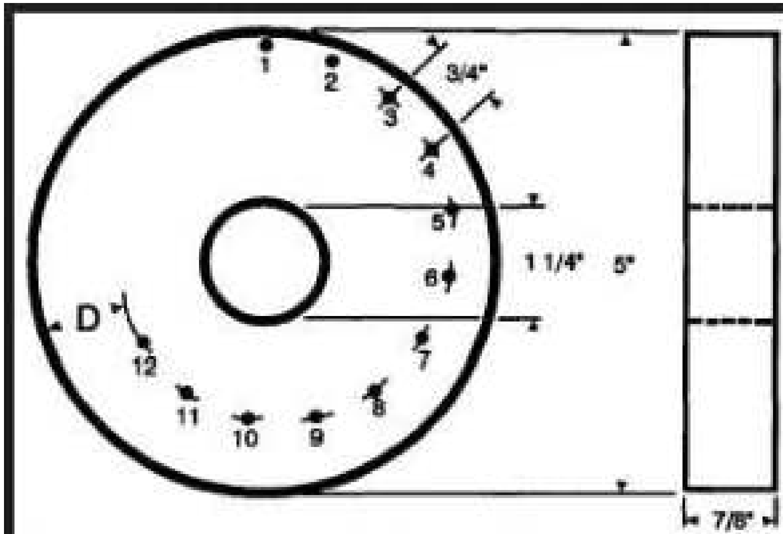
Checking devices in MPI

1. **Settling test** is also known as suspension concentration test. Test assures that proper concentration of particles is maintained in the liquid carrier.



Checking devices in MPI

2. Ketos ring is made of tool steel and is designed to show the effectiveness of MPI and the relative penetration based on the number of holes that display indications.



HOLE	1	2	3	4	5	6	7	8	9	10	11	12
DIAMETER	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
"D"	.07	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84

Checking devices in MPI

3. **Field indicator** is used to check residual magnetism on the system. Various devices used are,

- Gauss Meter or Hall Effect Gage
- Quantitative Quality Indicator (QQI)
- Pie Gage
- Slotted Strips

Checking devices in MPI

4. Suspension contamination test:

- The suspension solution should also be examined for evidence of contamination.
- Contamination primarily comes from inspected components. Oils, greases, sand, dust and dirt will be introduced to the system through components.
- Some contamination is to be expected but if the foreign matter exceeds 30 percent of the settled solids, the solution should be replaced

Checking devices in MPI

5. Ammeter accuracy: It is important that the ammeter provide consistent and correct readings.

- If the meter is reading low, over magnetization will occur and possibly result in excessive heat generation and melting of components.
- If ammeter readings are high, flux density could be too low to produce detectable indications.
- To verify ammeter accuracy, a calibrated ammeter is connected in series with the output circuit and values are compared to the equipment's ammeter values.
- The equipment meter is not to deviate from the calibrated ammeter more than ±10 percent or 50 amperes, whichever is greater.

Interpretations of MPI results

- The skill and experience of a well trained NDT examiner plays important role in performing MPI test properly.
- Proper interpretation involves finding out whether

1. Adherence of particles is due to the presence of cracks, or
2. Adherence is due to change in cross section, or
3. Particles are adhering to edges only.

Indications of MPI

- After proper interpretation of the result, the MPI examiner classifies the indications as

1. False indication
2. Non – relevant indications
3. Relevant indication

Indications of MPI

1. **False indication** can be produced due to improper handling, use of excessive magnetizing currents, improper pre cleaning of components etc…
2. **Non relevant indication** are the result of flux leakage due to geometrical changes of the test object.

- Examples of geometrical changes include splines, gear teeth, slots, key ways etc…

3. **Relevant indications** are produced by flux leakages due to discontinuities in the test specimen.

Advantages of MPI

- It is quick and relatively uncomplicated
- It gives immediate indications of defects
- It shows surface and near surface defects
- The method can be adapted for site or workshop use
- It is inexpensive compared to radiography method
- Large or small objects can be examined
- Elaborate pre-cleaning is not necessary

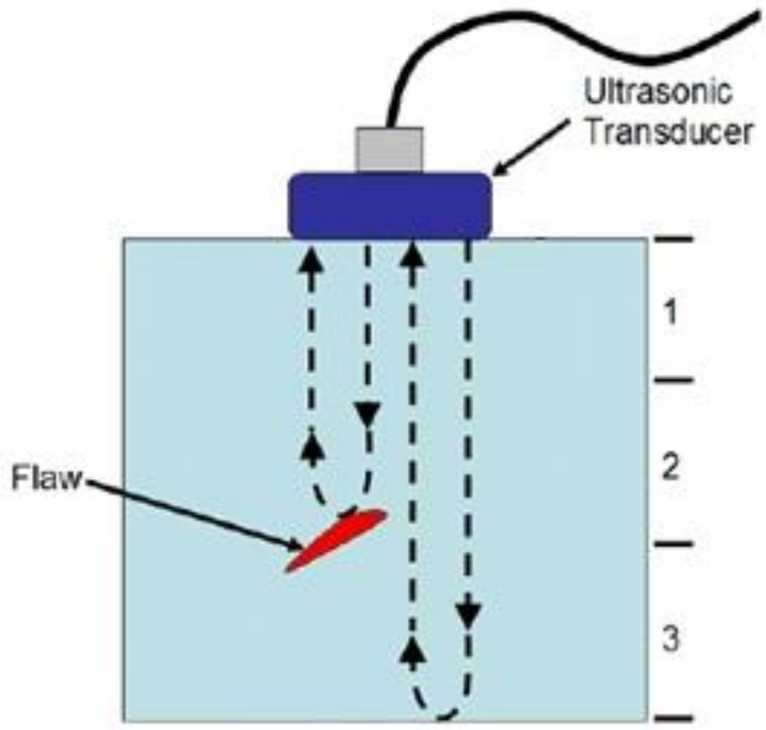
Disadvantages of MPI

- It is restricted to ferromagnetic materials
- Only surface and near surface cracks can be detected
- Most methods need supply of electricity
- It is sometimes unclear whether the magnetic field is sufficiently strong to give good indications
- The method cannot be used if a thick paint coating is present
- False or non-relevant indications, are probable, and thus interpretation is a skilled task
- Magnetic particle suspension fluids are flammable and hazardous in nature.

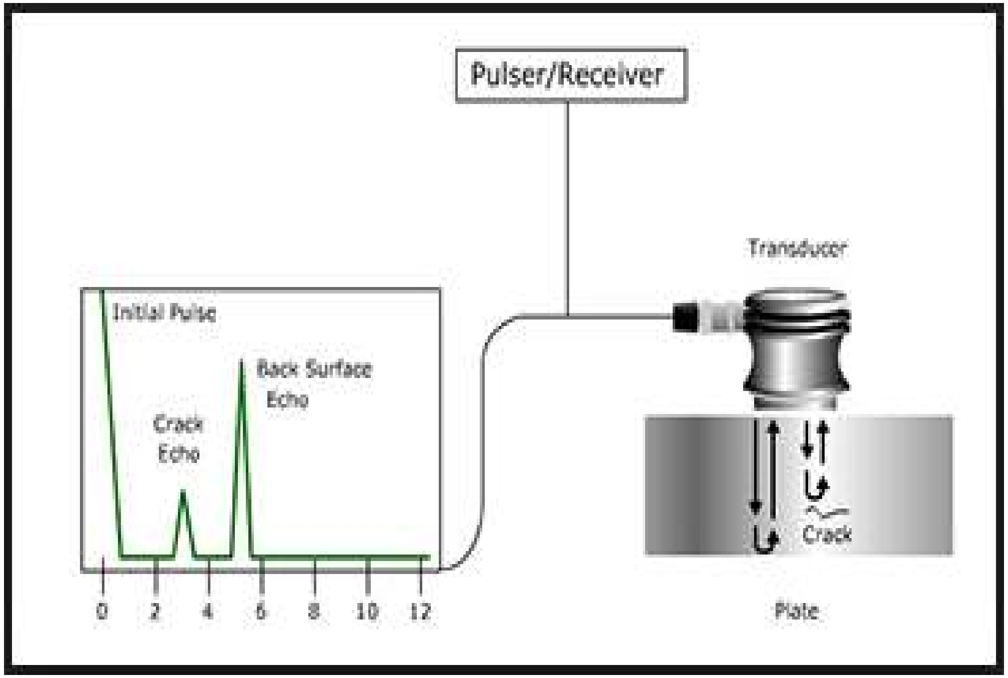
MODULE 4
Ultrasonic Testing

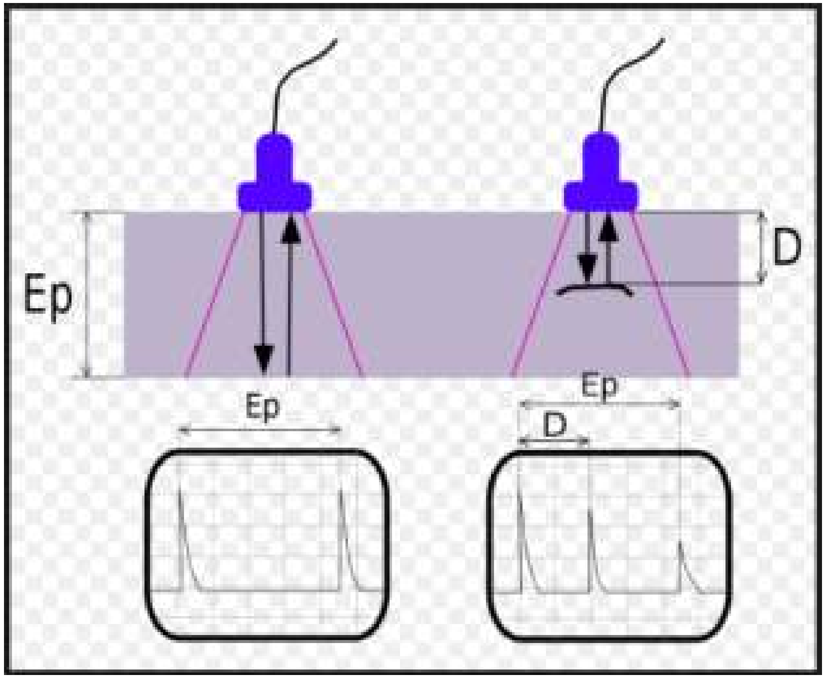
Ultrasonic testing

- **Ultrasonic testing** (**UT**) is a type of non-destructive testing technique based on the propagation of ultrasonic waves to the object or material to be tested



UT


Pulser/Receiver
Transducer
Initial Pulse
Back Surface
Echo
Crack
Echo
0
2
4
6
8
10
12
Crack
Plate


Ep
D
Ep
Ep
D

Ultrasonic waves

- Sound waves having frequency above 20kHz are termed as ultrasonic waves.
- Usual frequency range for NDT of materials is 0.5 – 10 MHz
- To detect fine cracks high frequency waves are required.

Working principle

- UT system consists of a pulser, reciever, transducer & display devices.
- Pulser/ reciever is an electronic device that can produce high frequency ultrasonic waves.
- Sound energy propagates through the material in the form of waves.
- When the sound wave met with a flaw/ crack/ discontinuity, it will reflect back to the receiver.
- The reflected wave is then converted into electrical energy by a transducer, and is then displayed.

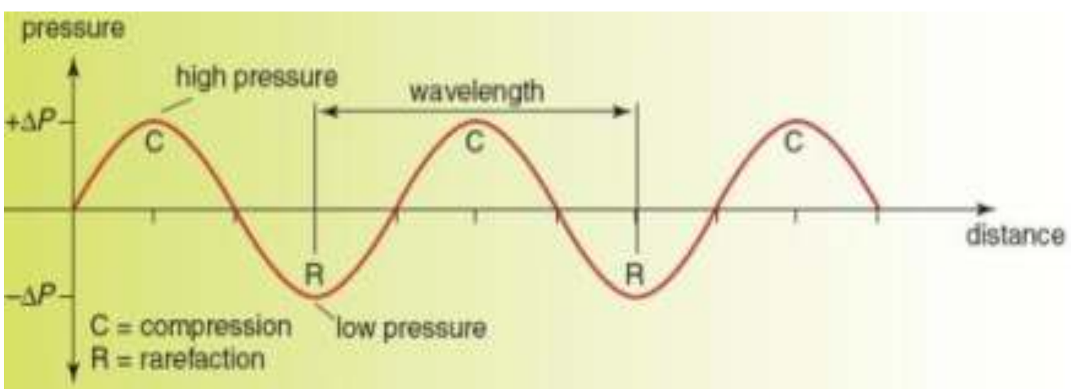
Types of ultrasonic waves

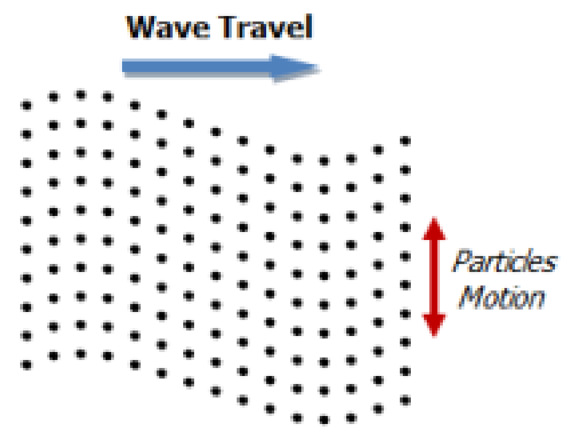
1. Transverse or Shear ultrasonic Waves
2. Longitudinal or Compressional or Pressure ultrasonic Waves
3. Surface or Rayleigh Waves
4. Lamb or Flexural or Plate Waves

Types of ultrasonic waves

1. **Transverse or Shear type ultrasonic waves**

- In transverse waves, particles of the medium vibrate perpendicular to the direction of waves propagation.
- These waves can propagate through solids.





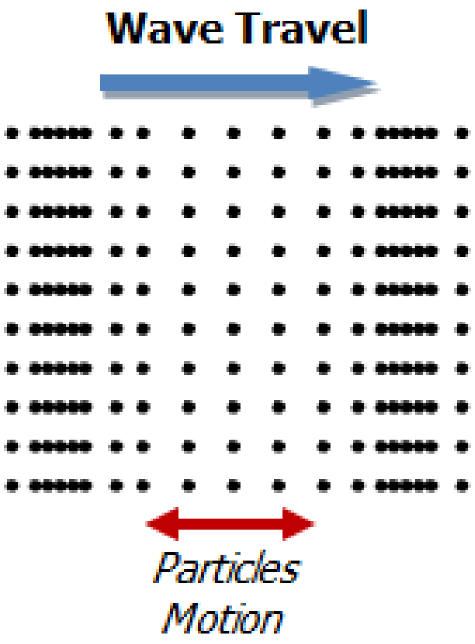
Types of ultrasonic waves

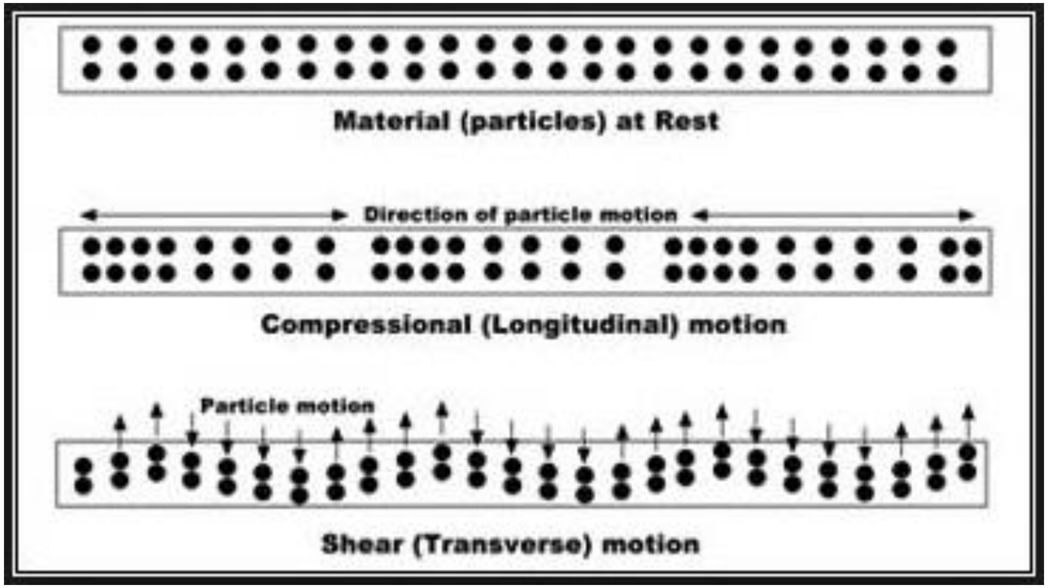
2. **Longitudinal or Compressional or Pressure type ultrasonic waves**

- In the longitudinal waves particles of medium vibrate back and forth parallel to the direction of propagation of wave.
- These waves propagate through the medium as a series of alternate compression and rarefaction.
- These waves are most widely used in the ultrasonic inspection of materials.

Types of ultrasonic waves

2. Longitudinal or Compressional or Pressure type ultrasonic waves

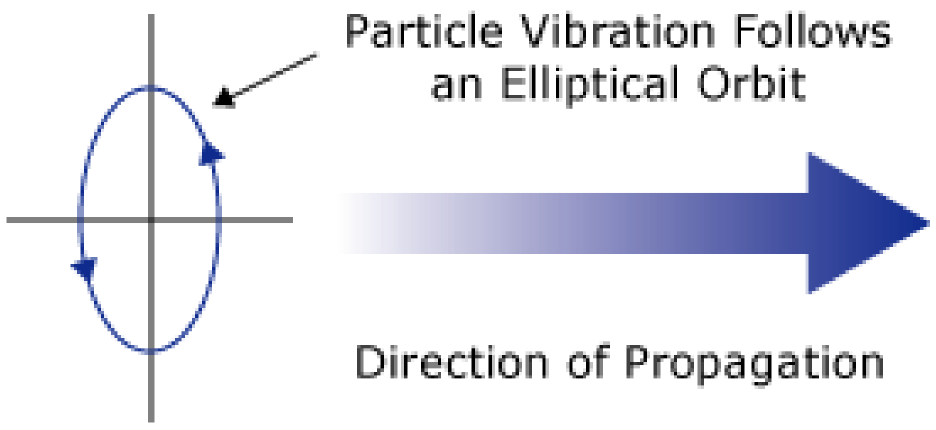




Types of ultrasonic waves

3. **Surface or Rayleigh waves**

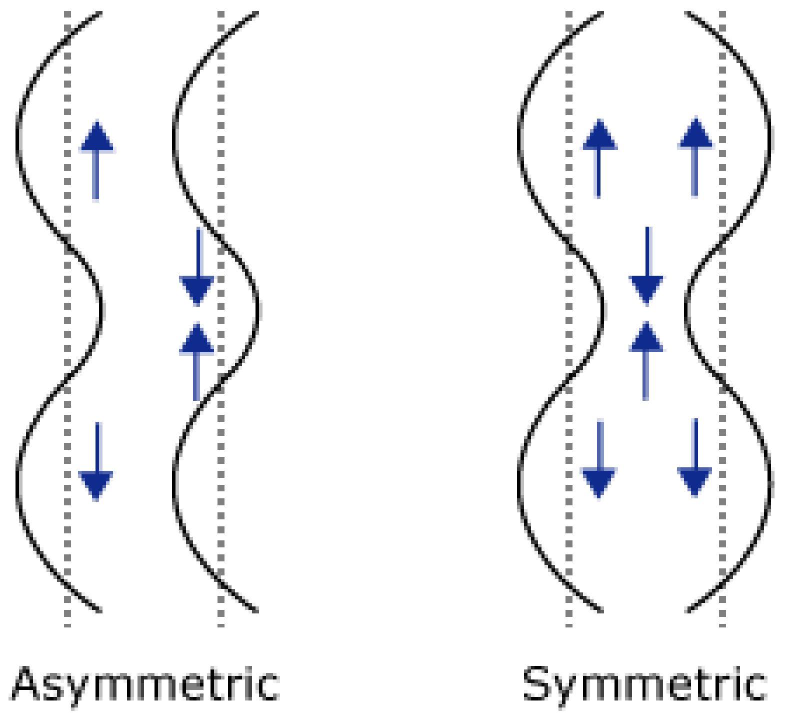
- Surface waves combines both a longitudinal and transverse motion to create an elliptical orbit motion



Types of ultrasonic waves

4. Lamb or Flexural or Plate Waves

- Lamb waves are complex shaped waves that vibrate parallel to the test surface throughout the thickness of the material.

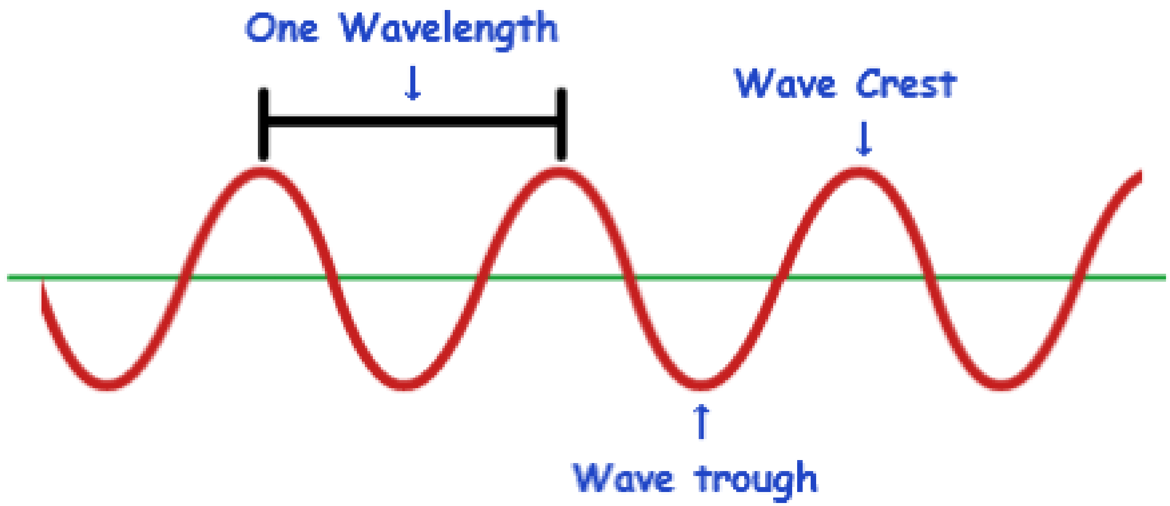


Wave type & particle vibration

Wave Type	Particle Vibration
Longitudinal (Compression)	Parallel to wave direction
Transverse (Shear)	Perpendicular to wave direction
Surface - Rayleigh	Elliptical orbit - symmetrical mode
Plate Wave - Lamb	Component perpendicular to surface

Wavelength

- Wave length is the distance between two successive crests or troughs in a transverse wave.
- It is also defined as the distance between any two nearest particles on the wave having same phase.



Time period (T)

- Time period is the time taken by a wave to travel a distance equal to its wavelength.

Frequency (n)

- Frequency is defined as the number of waves produced in one second.

$$n = 1/T$$

Velocity (V)

- Distance travelled by a wave in one second is called the velocity of propagation.
- $$V = \frac{\text{Distance travelled}}{\text{Time taken}}$$

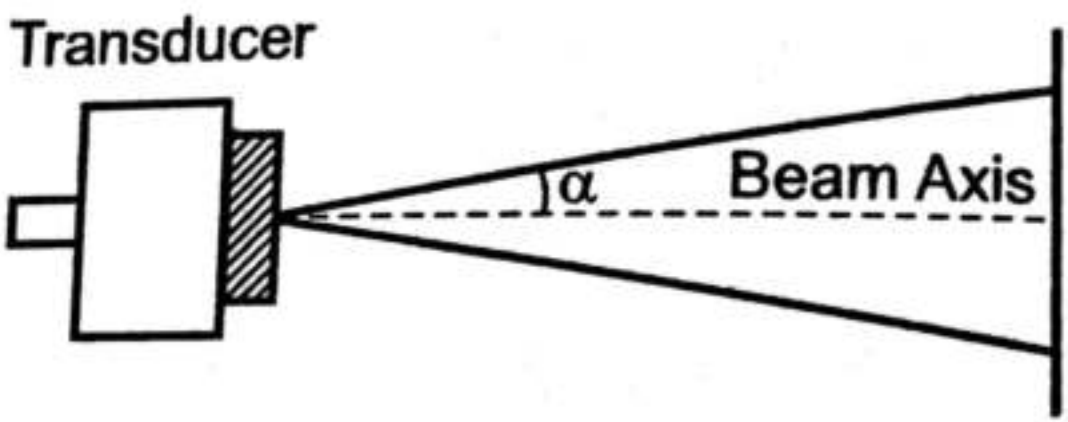
  = ¶ / T = n¶
- Therefore **V = n¶**

Reflection

- When sound travels in a given medium, it strikes the surface of another medium and bounces back in some other direction. This phenomenon is called the reflection of sound.
- The waves are called the incident and reflected sound waves.

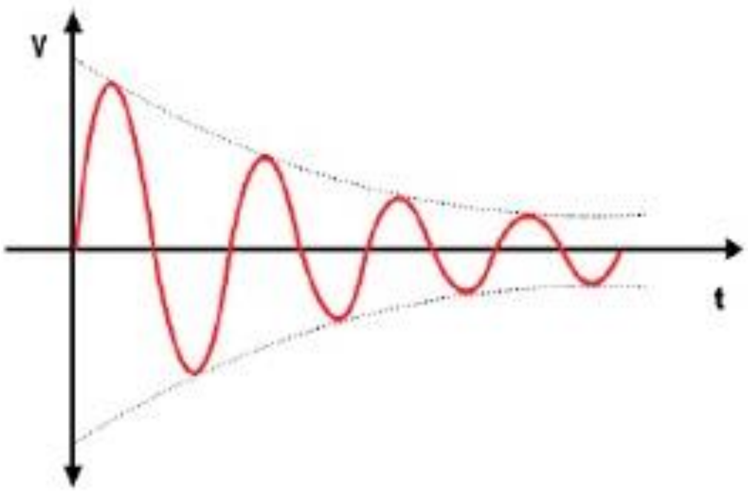
Beam spread & beam divergence (α)

- Beam spread is the measure of the whole angle from side to side of the main lobe of the sound beam.
- Beam divergence (α) is the measure of angle from one side of the sound beam to the central axis of the beam.



Attenuation of sound wave

- Attenuation generally refers to reduction in strength of signal or wave.
- When sound wave travels through a medium, its intensity reduces with distance.
- Attenuation is the combined effect of scattering and absorption.



Ultrasonic testing techniques

1. Transmission method
2. Pulse – echo method

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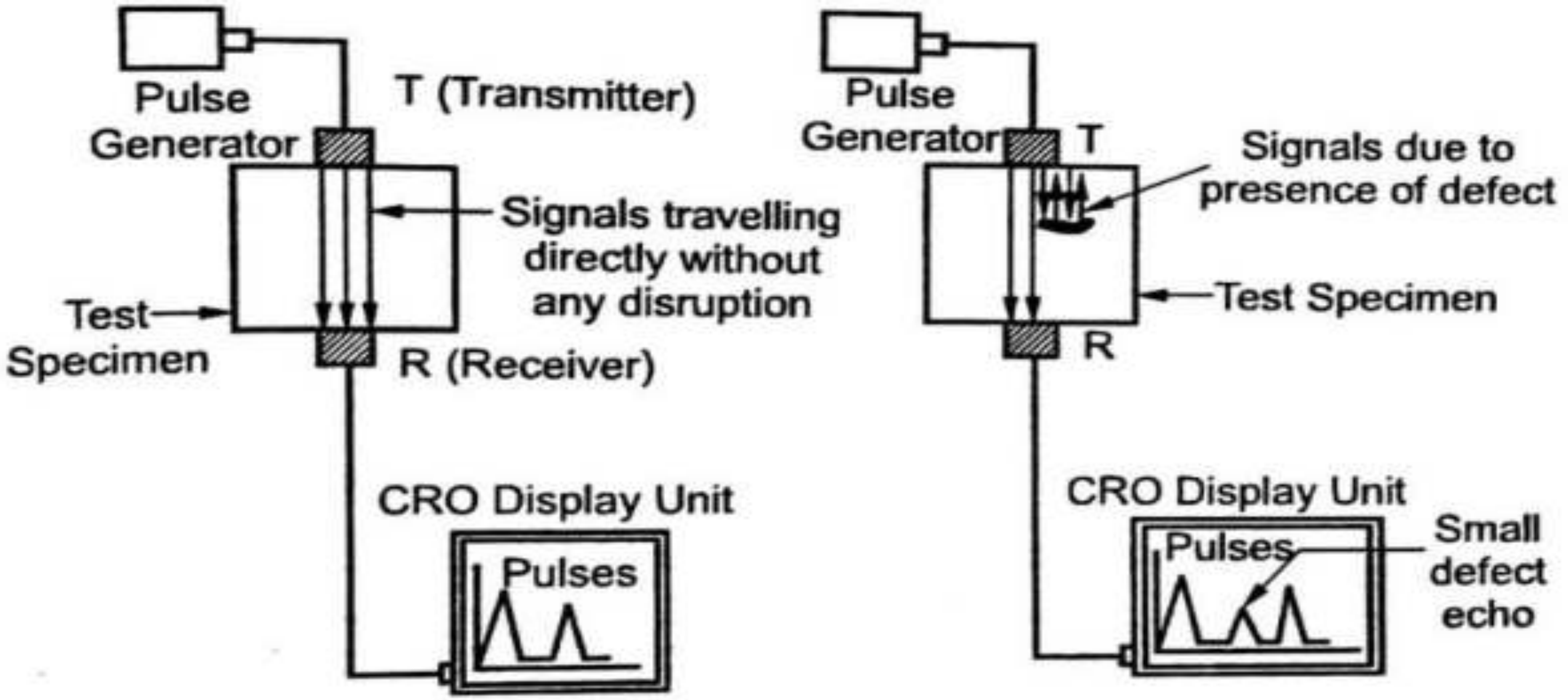
Ultrasonic testing techniques

1. Transmission method

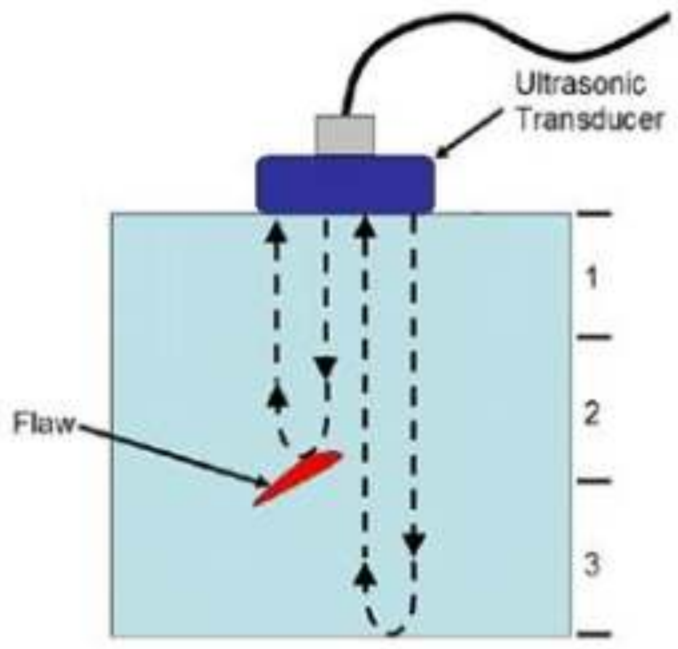


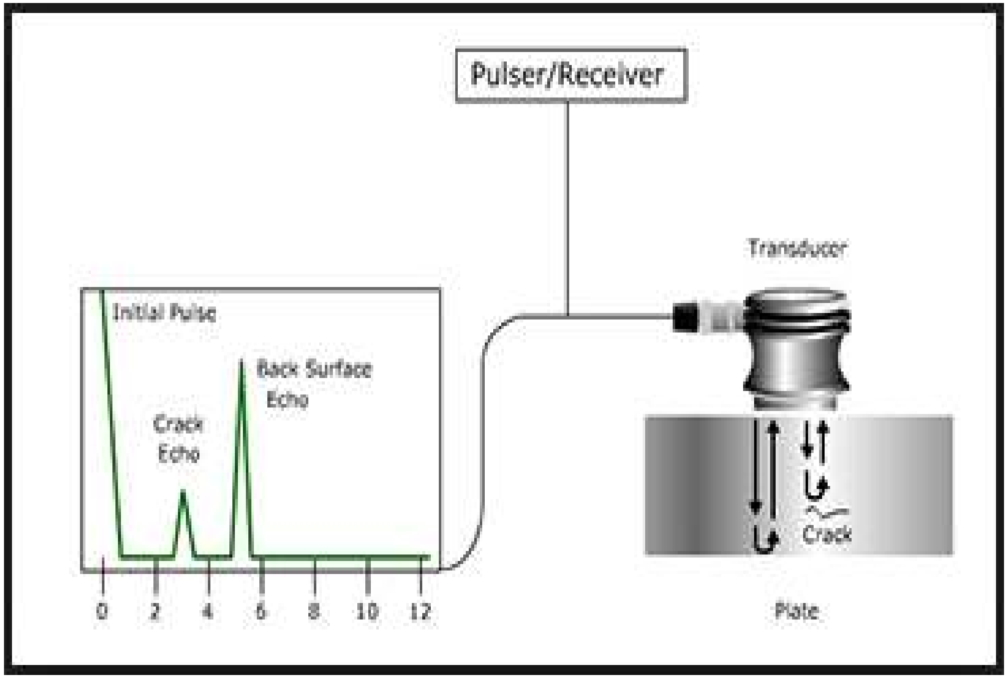
(a) Transmission of waves through defect free Specimen

(b) Transmission of waves through specimen with defect

Ultrasonic testing techniques

2. Pulse – echo method





Assignment # 1

1. With neat sketches explain 6 different types of UT techniques.
2. With neat sketch explain the working of ultrasonic transducer.
3. Explain about various instruments used in UT.

Submit on or before – 28.09.2018

Assignment # 2

1. Write short notes on calibration of UT equipments & importance of using reference block with artificially created defects.
2. With neat sketch, explain about

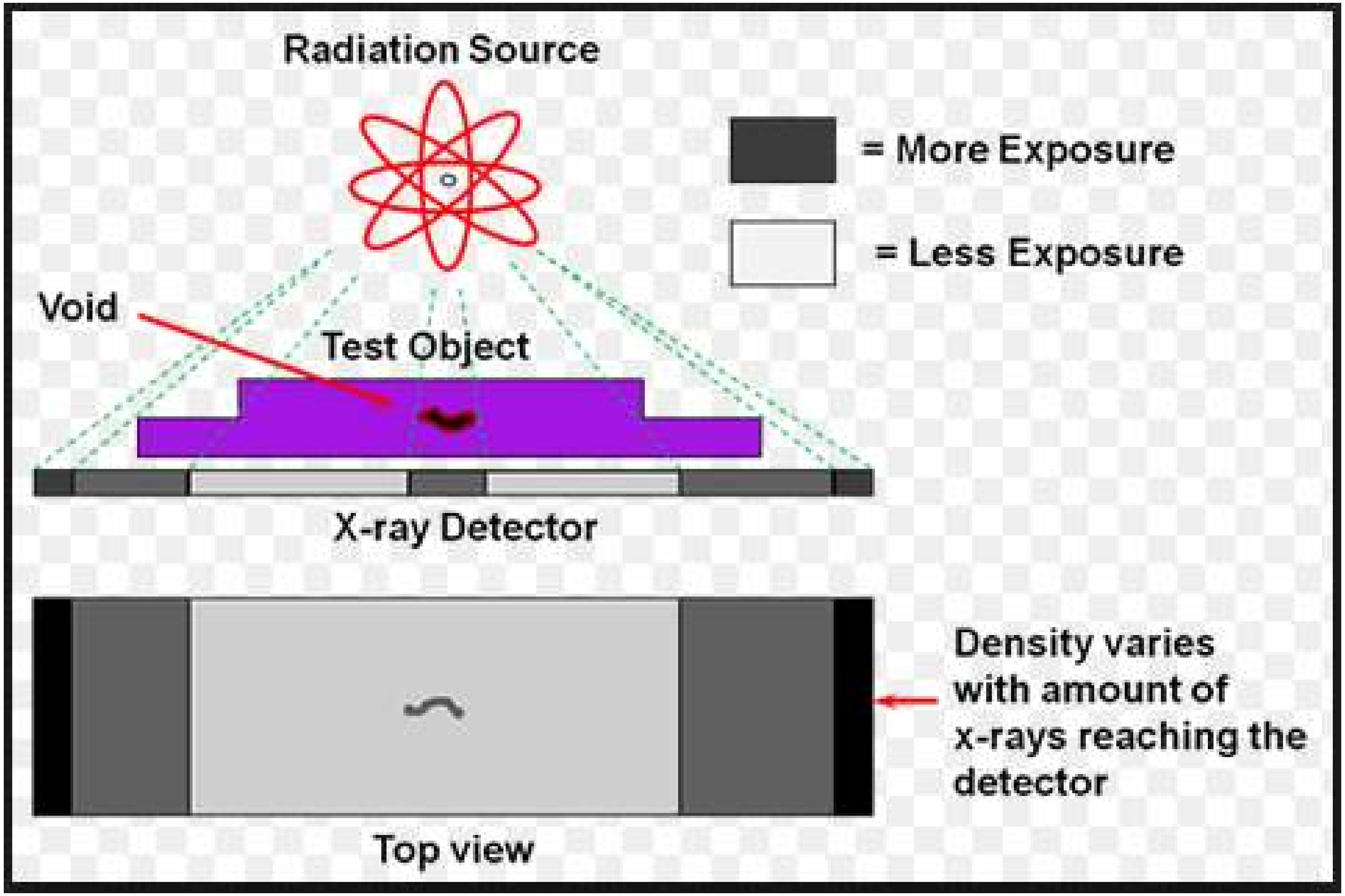
   A) A – Scan B) B – Scan C) C – Scan
3. Explain Time of Flight Diffraction (TOFD) in detail.
4. List the advantages & disadvantages of UT.

Submit on or before – 31.10.2018 (Wednesday)

MODULE 5

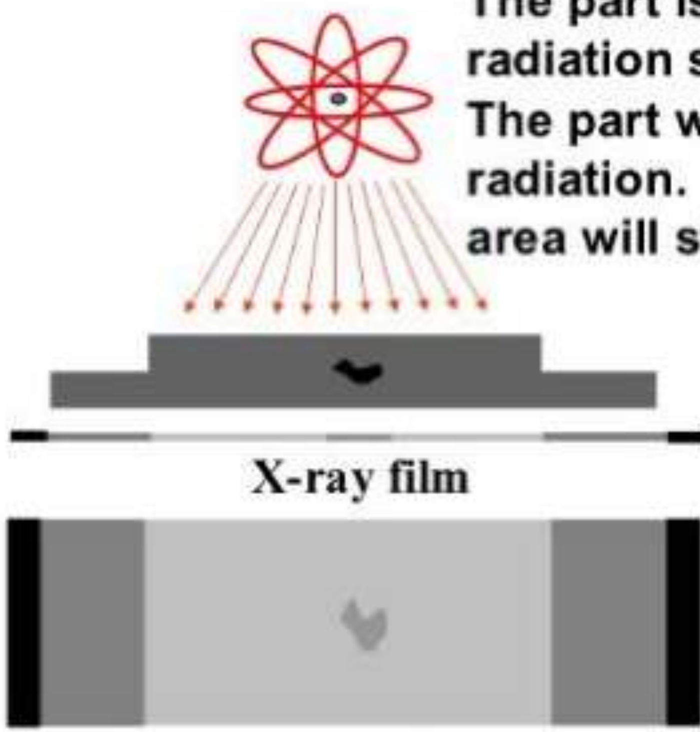
Radiography Testing

Radiography Testing (RT)



General Principles of Radiography

The part is placed between the radiation source and a piece of film. The part will stop some of the radiation. Thicker and more dense area will stop more of the radiation.



Top view of developed film

The film darkness (density) will vary with the amount of radiation reaching the film through the test object.

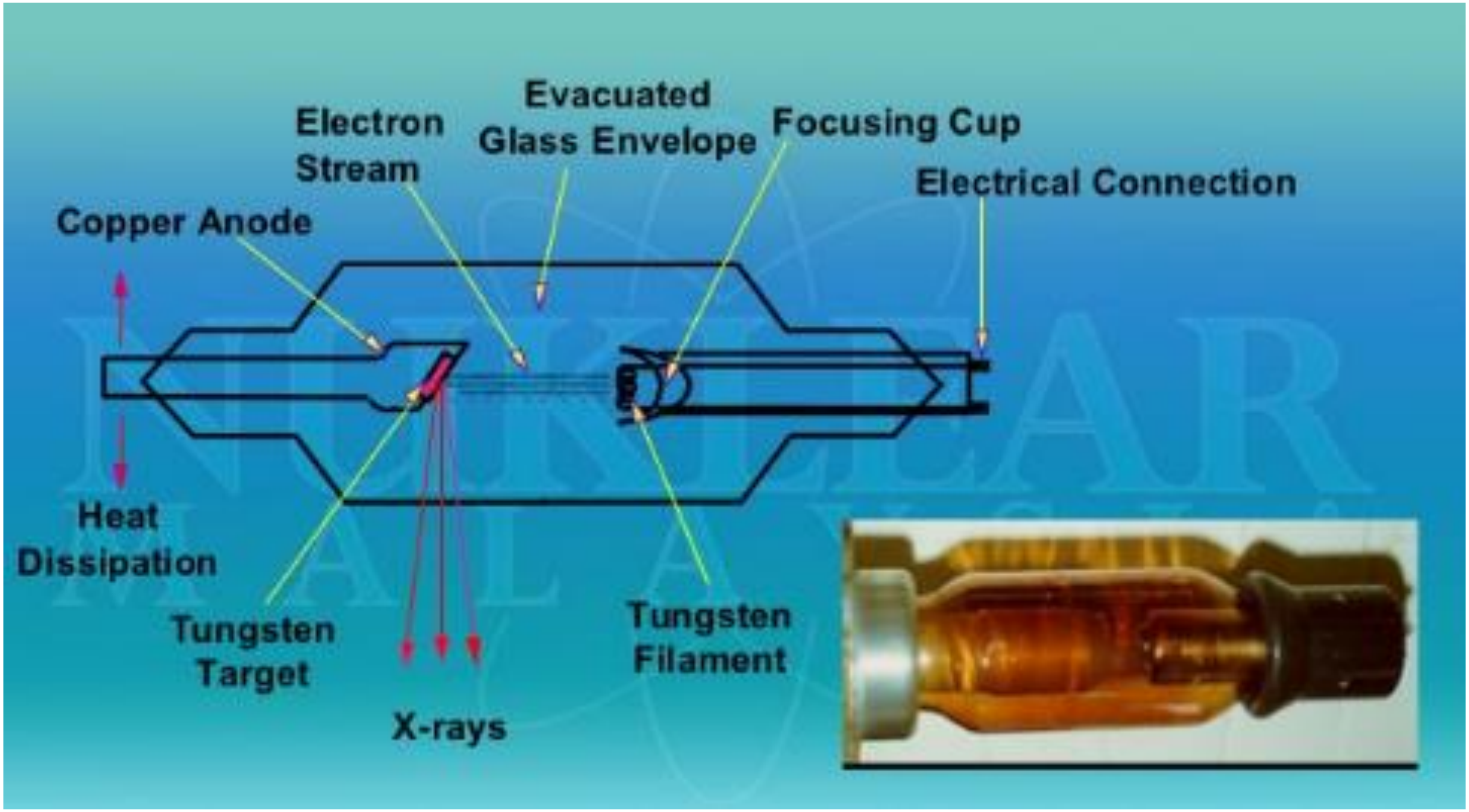
= less exposure

= more exposure

Electro magnetic radiation sources

1. X-Ray source
2. Gamma ray source

X-Ray Source



Evacuated Glass Envelope
Electron Stream
Focusing Cup
Electrical Connection
Copper Anode
Heat Dissipation
Tungsten Target
X-rays
Tungsten Filament

Production of X-Rays

1. First performed by Roentgen (1895)
2. Generates accelerated electrons between anode and cathode by maintaining high voltage difference.
3. X-Rays are produced when fast moving electrons collides with a matter.
4. Upon collision about 99% of kinetic energy got converted to heat energy.
5. Less than 1% is converted to X-Rays

High energy X-Ray source

1. High energy X Rays or HEX rays are high intensity X rays whose energy value is 1 MeV.
2. Used for examining thick specimens.
3. Advantages - Increased penetration, sensitivity and resolution.

Gamma ray source

1. Gamma rays are electro magnetic radiation emitted from an unstable nucleus.
2. Gamma rays are produced by 4 different nuclear reactions – Fission, fusion, alpha decay and gamma decay.

Gamma ray sources

Radionuclides	γ Energies (MeV)	Half-life	Optimum Steel Thickness of Test Material (mm)
^{60}Co	High (1.17 and 1.3)	5.3 yrs	50-150
^{137}Cs	High (0.662)	30 yrs	50-100
^{192}Ir	Medium (0.2-1.4)	74 days	10-70
^{75}Se	Medium (0.12-0.97)	120 days	4-28

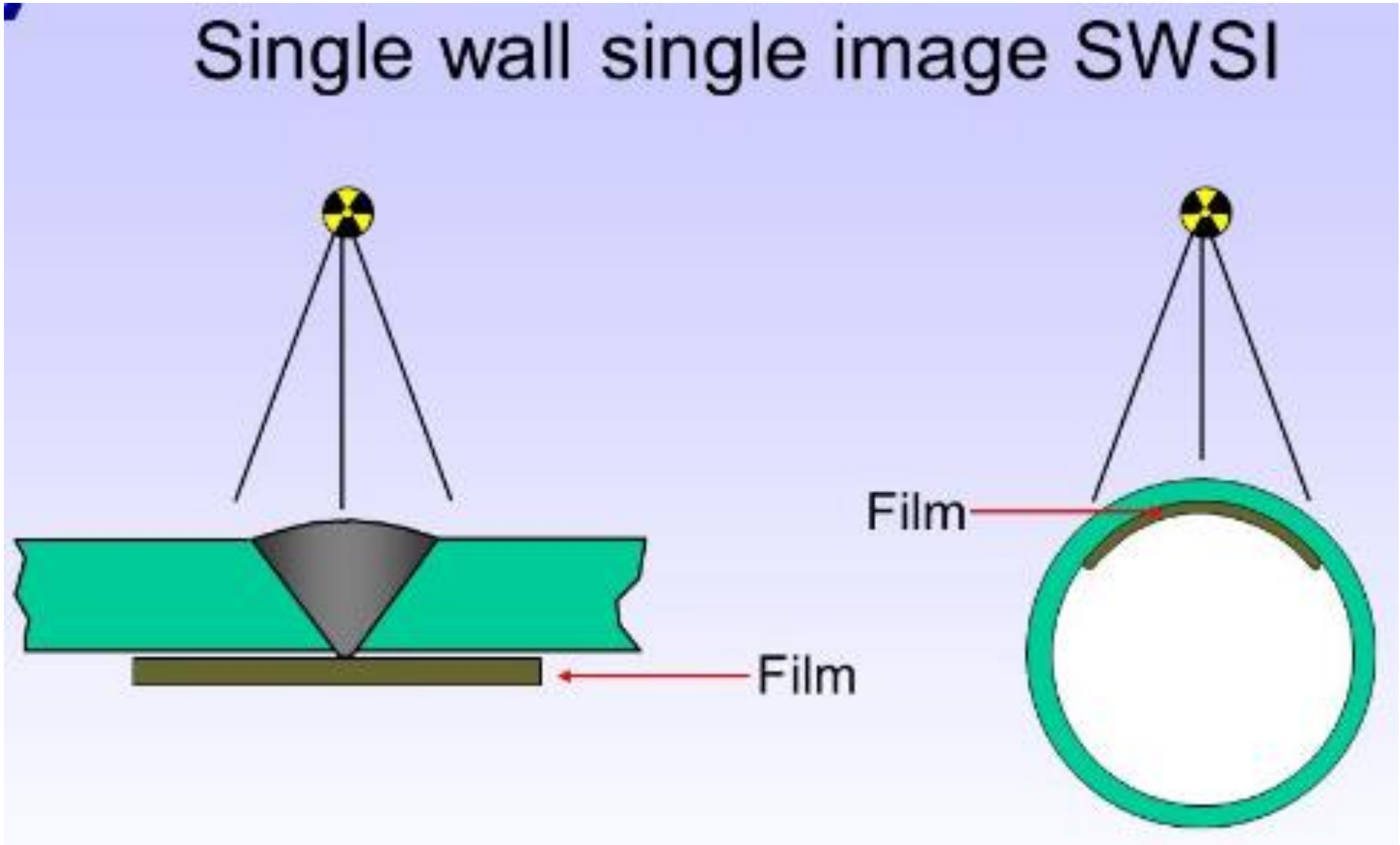
Properties of X rays and Gamma rays

1. They are invisible and travels at the speed of light.
2. Propagates through straight path.
3. Not affected by electric and magnetic fields
4. Capable of ionizing gases
5. Capable of blackening photographic film
6. Can damage living cells & produce genetic mutation
7. Exhibit wave properties like reflection, refraction & diffraction.

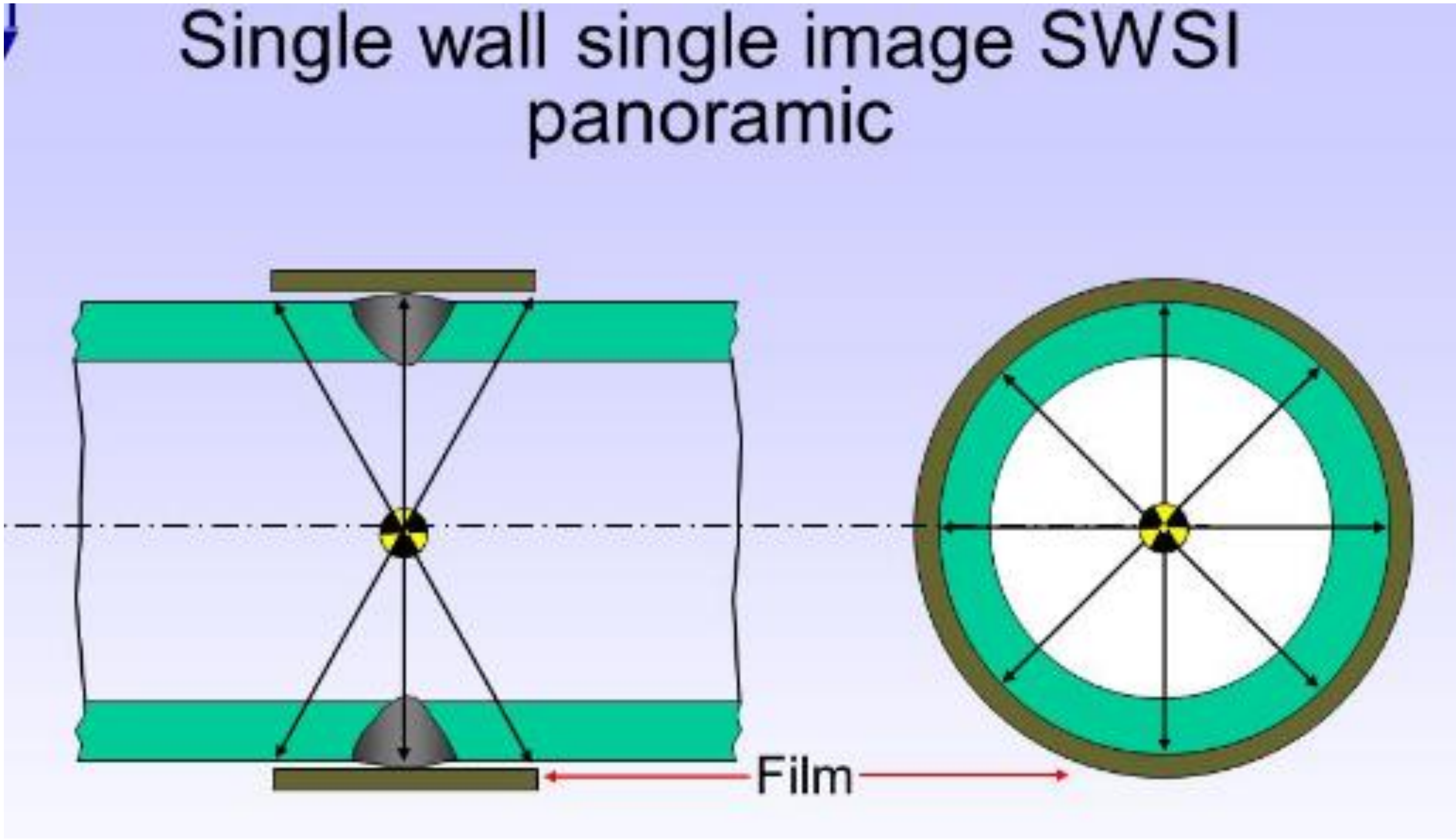
Inspection techniques in radiography

1. Single wall single image technique (SWSI)
2. Double wall single image technique (DWSI)
3. Double wall double image technique (DWDI)

Inspection techniques in radiography
1. a. SWSI – Flat Technique

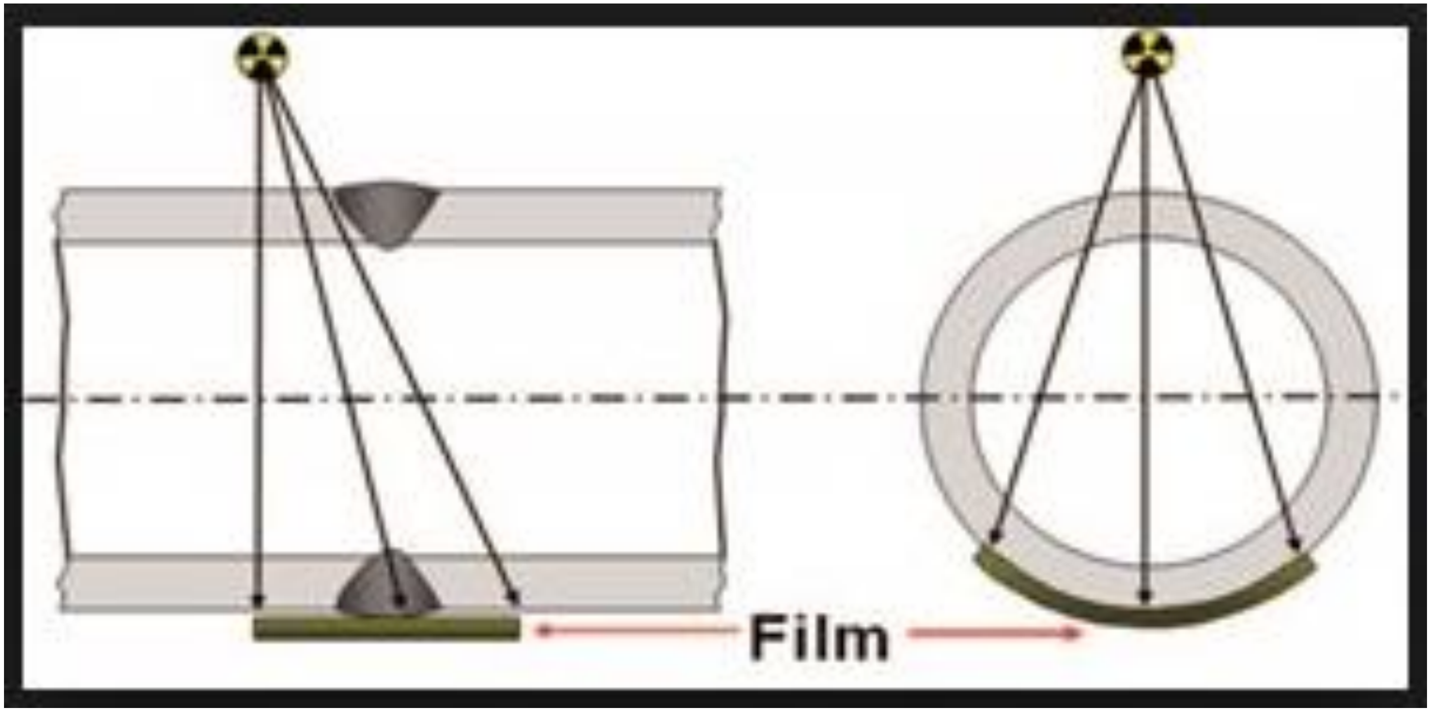


Inspection techniques in radiography
1. b. SWSI – Panoramic Technique

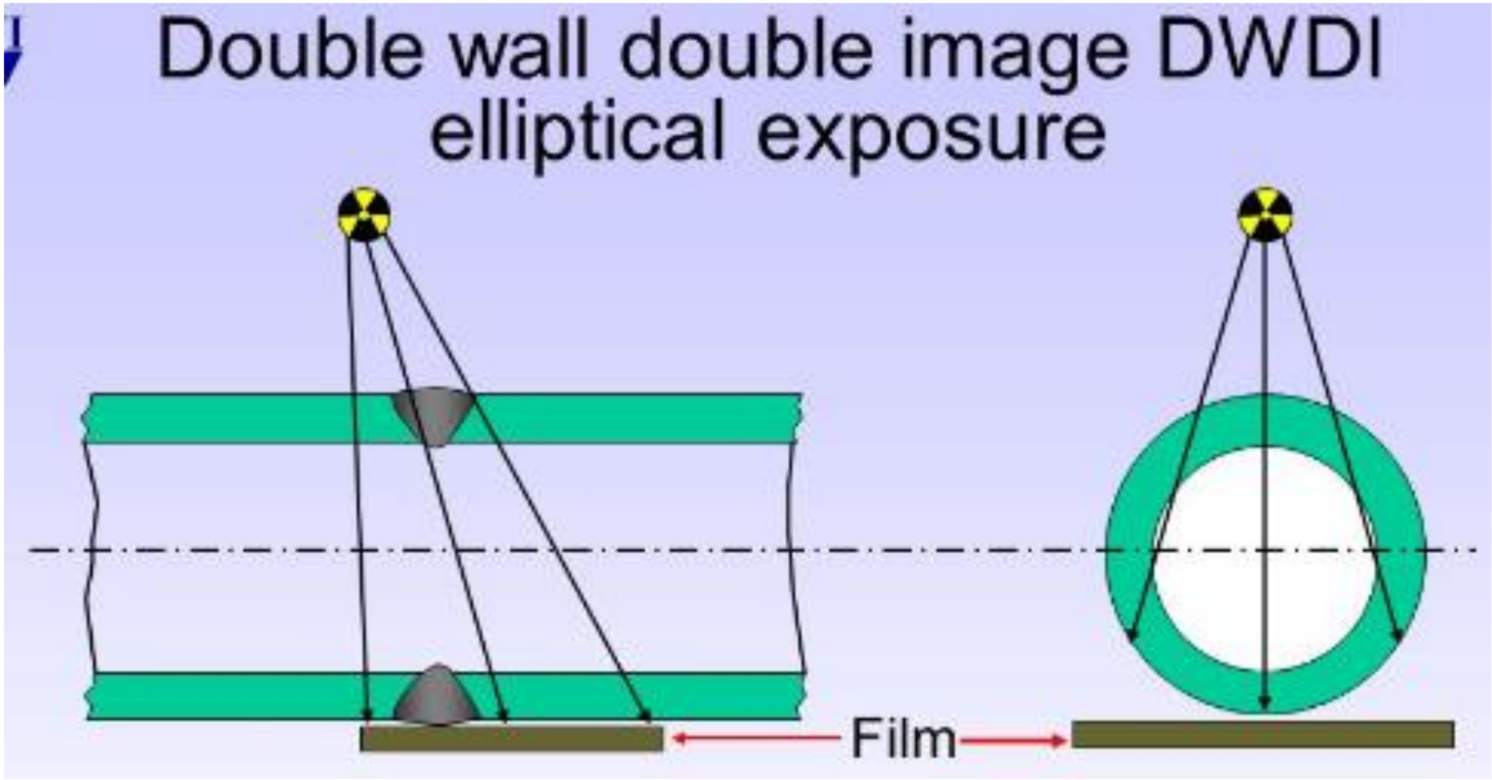


Inspection techniques in radiography

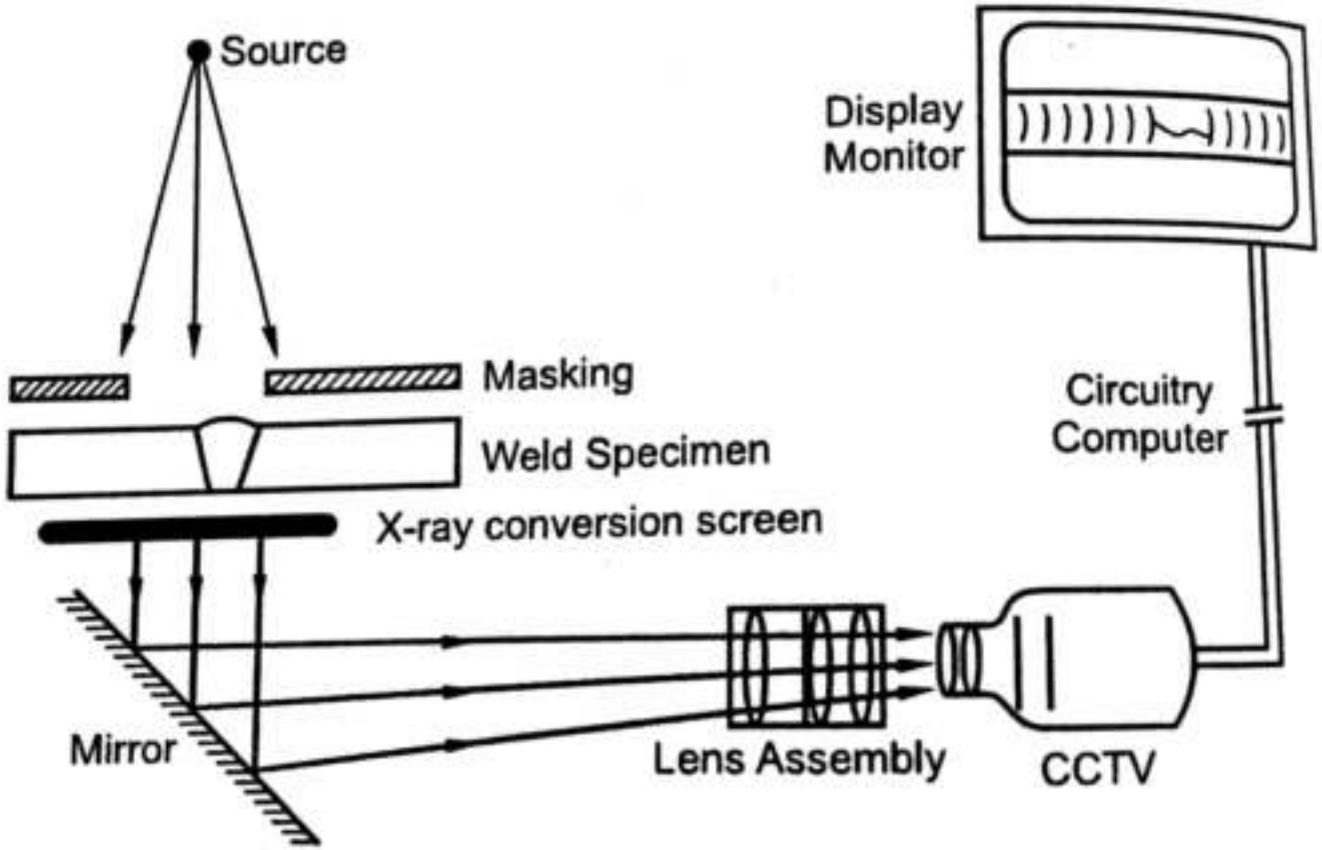
2. Double Wall Single Image (DWSI)



Inspection techniques in radiography
3. Double Wall Double Image (DWDI)



Real time radiography



Real-Time Radiography

- Real-Time Radiography (RTR) is a term used to describe a form of radiography that allows electronic images to be captured and viewed in real time.
- Because image acquisition is almost instantaneous, X-ray images can be viewed as the part is moved and rotated.
- Manipulating the part can be advantageous for several reasons:
  - It may be possible to image the entire component with one exposure.
  - Viewing the internal structure of the part from different angular prospectives can provide additional data for analysis.
  - Time of inspection can often be reduced.

Real time radiography

Films used in radiography

1. Made of 0.0005 inch thick polyester type transparent material.
2. Emulsion containing Silver Halide (Silver Bromide or Silver Chloride) with a binder (Gelatin) is applied to both sides of the film.
3. When exposed to radiation, silver halide turns to black.

Speed of films used in radiography

Based on exposure time, films are classified into

1. **High Speed Film** has coarse grains of silver halide which reacts with radiation at a faster rate.

- Less exposure time required.
- Produces poor quality images.

2. **Low Speed Film** has fine grains which exhibits slow reaction to radiation.

- More exposure time is required for low speed films.
- Produces good quality images

Types of films used in radiography

Class	Characteristics
Class I	Extra fine grain, Slow speed
Class II	Fine grain, Medium speed
Class III	High speed
Class IV	Fluorescent type, Not for industrial radiography

Quality of films used in radiography

Quality of film depends on two factors:

1. Film density
2. Film graininess

Quality of films used in radiography

1. Film density:

- Film density/ light transmission density/ optical density is a measure of degree of film darkening.

$$D = \log \frac{I_0}{I_t}$$

I_o = Light intensity which strikes the film

I_t = Transmitted light intensity

D = Film density

Quality of films used in radiography

2. Film graininess

- Fine grain film is capable of producing high quality images.

Screens used in radiography

- Radiographic films when exposed to radiation, absorb only small amount of radiations.
- In order to fully utilize the radiation and enhance photographic effect, screens are used in combination with films.
- **Types of screens:**

1. Metal foil screens
2. Fluorescent salt screens

Metal foil screen

- Metal foil screens are generally lead foil screen.
- They are used in pairs by sandwiching the film between them.
- Side of film facing the source is the front screen and the other one is called back screen.

ADVANTAGES

1. Improved photographic action
2. Soft and scattered radiations are absorbed more effectively
3. Increased quality of image
4. Exposure time is reduced.

Fluorescent intensifying or salt screen

- It consists of a thin layer of powdered fluorescent material (E.g: Barium lead sulfate) mixed with a suitable binder, which is coated on a plastic base.
- The fluorescent material emits visible or UV rays when exposed to radiations.
- Exposure time required is greatly reduced.

Quality of radiography

- Quality of radiography is measured using 4 factors:

1. Density
2. Contrast
3. Definition
4. Sensitivity

Quality of good radiography

1. **Density:** Radiographic density is the measure of the degree of film darkening.

$$D = \log \frac{I_0}{I_t}$$

Io = Light intensity which strikes the film

It = Transmitted light intensity

D = Film density

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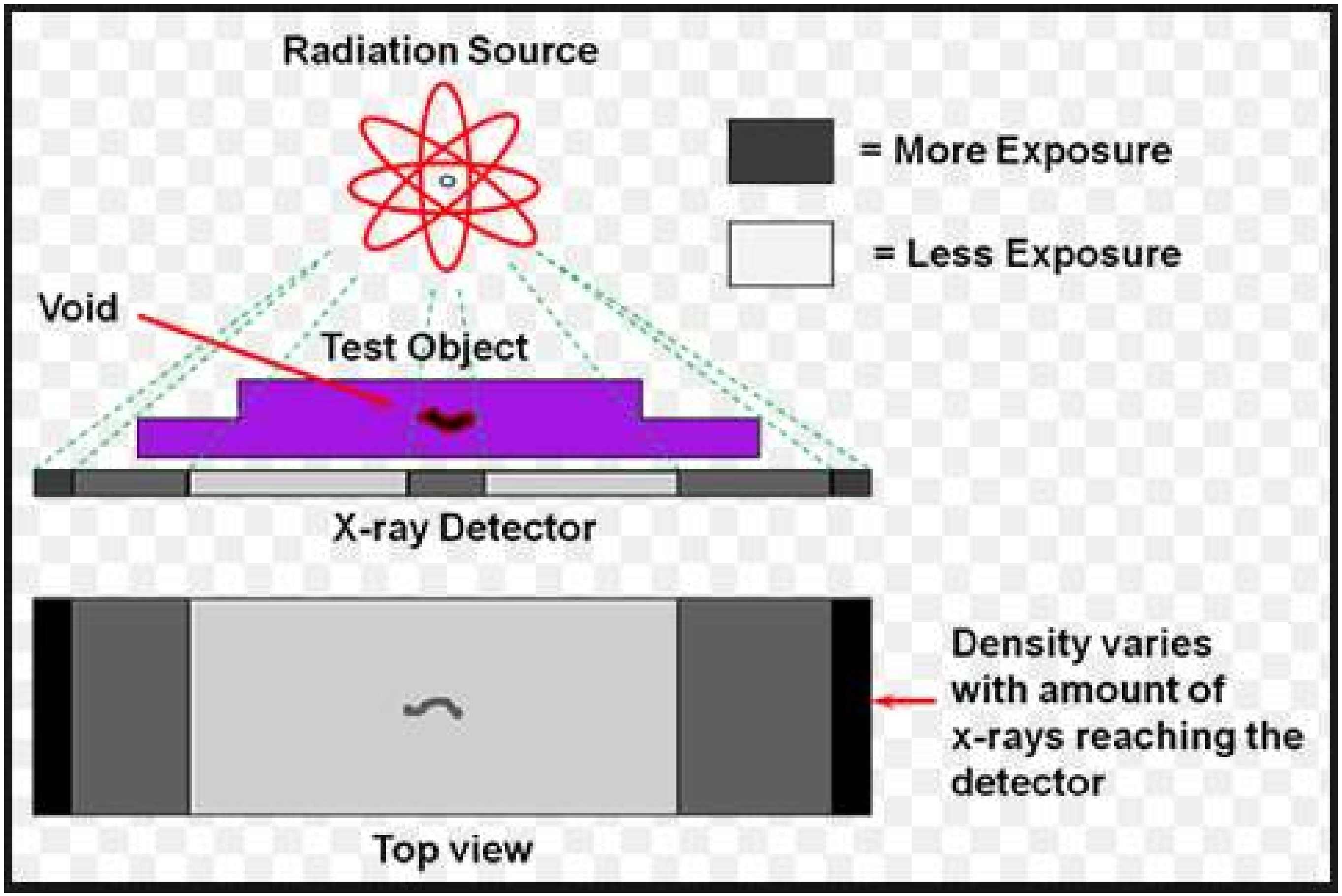
Quality of good radiography

2. Contrast is the degree of density difference between adjacent areas on a radiography film.

- Contrast between different parts of the film is what forms the image.
- The greater the contrast, the more visible the image becomes.

Quality of good radiography

2. Contrast



Quality of good radiography

Definition & Sensitivity

- Definition and sensitivity are measures of quality of image in terms of the smallest detail or discontinuity that may be detected.
- Quality of radiographic film and equipment greatly affects the definition and sensitivity of the process.

Film processing

- Film processing involves 5 steps:

1. Development
2. Stopping the development
3. Fixing
4. Washing
5. Drying

Film processing

1. **Development -** The developing agent applied (E.g: Hydroquinone or Phenidone) converts the silver halide grains to metallic silver.

- Grains that have been exposed to the radiation develop more rapidly, but given enough time the developer will convert all the silver ions into silver metal.
- Proper temperature control is needed to convert exposed grains to pure silver while keeping unexposed grains as silver halide crystals.

Film processing

2. **Stopping the development** - The stop bath simply stops the development process by diluting and washing the developer away with water.
3. **Fixing** - Unexposed silver halide crystals are removed by the fixing bath in acidic solution. The fixer dissolves only silver halide crystals, leaving the silver metal behind.
4. **Washing** - The film is washed with water to remove all the processing chemicals.
5. **Drying** - The film is dried for viewing

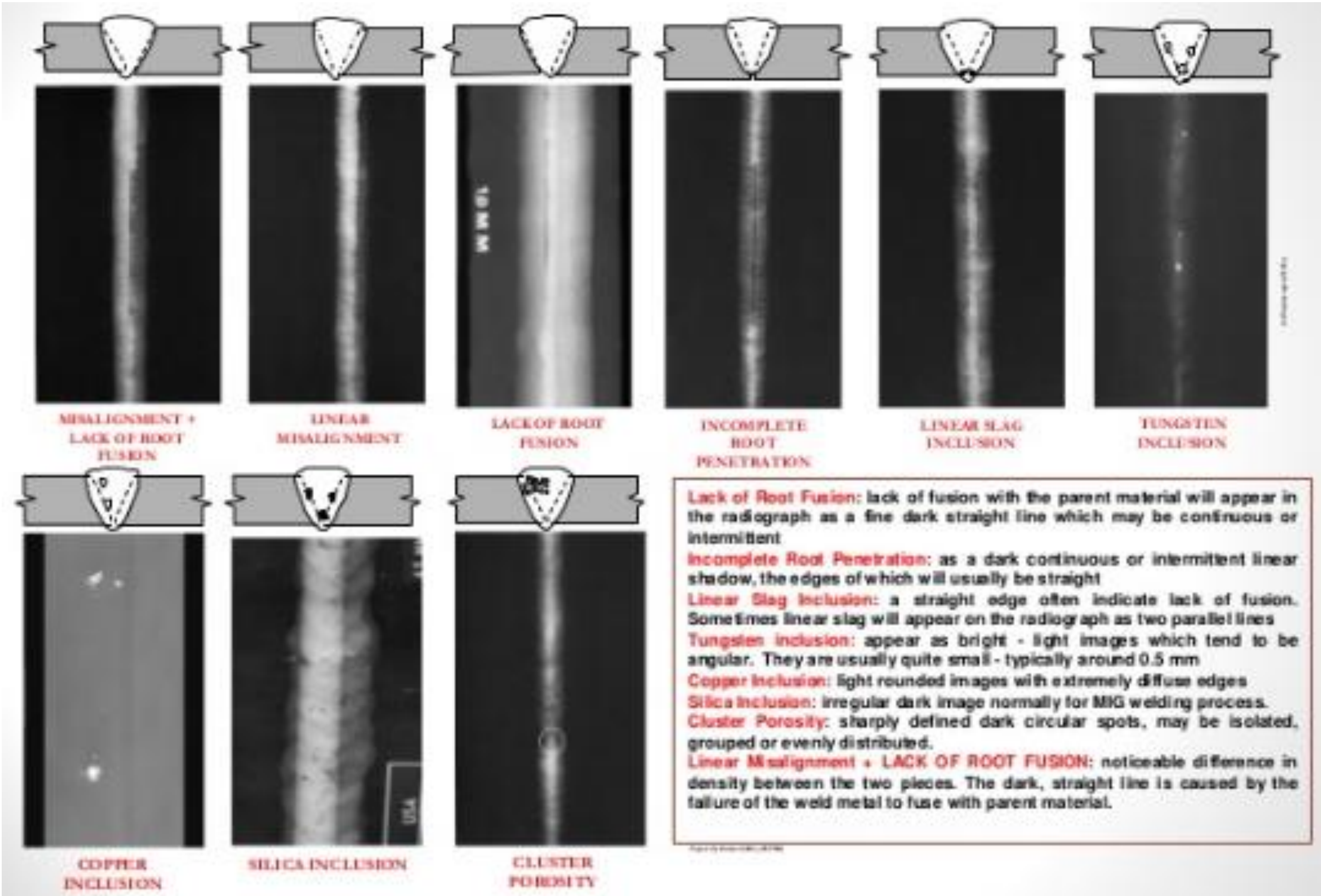
Evaluation of results

- Image of a discontinuity (void or inclusion) in a test specimen is shown in contrast compared to its surroundings.
- A crack or void in a component results in darker image compared to its surroundings
- A foreign particle can be detected by lighter image

Interpretation of results

- Gas porosity – Appears as round or elongated dark spots
- Slag inclusion – Appears as dark irregular shapes
- Incomplete penetration of weld joint – Appears as continuous or intermittent dark lines of uniform width , occurring in the middle of the weld.
- Cracks – Appears as sharp lines with tapered ends
- Foreign metal inclusion – Appears as white areas of round or irregular shapes

Interpretation of welding radiographs



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Safety aspects required in radiography

- Protection of person
- Monitoring radiation dosage

Safety aspects required in radiography

- **Protection of person**

1. **Exposure time**: Reduce exposure time to radiations to as minimum as possible.

- Time of handling can be reduced by providing proper training & by adopting fast work techniques.

2. **Distance**: Radiation intensity reduces as the distance from source increases. Worker should stay as far as possible from the source.

Safety aspects required in radiography

- **Protection of person**

3. **Shielding**: Provide proper shielding between operator and source.

- Dense & heavy shielding provides improved protection against radiation.
- E,g.: Steel.

Safety aspects required in radiography

- **Monitoring radiation dosage**

1. Film badge:

- Most common type of radiation dosimeter used.
- Works by darkening of x-ray film in proportion to radiation absorbed.
- Cheap

Safety aspects required in radiography

- Monitoring radiation dosage

2. Thermoluminescent dosimeters
3. Direct reading / Pen dosimeters

Applications of radiography testing

- Radiography can be used to inspect most types of solid materials both ferrous and non-ferrous alloys as well as nonmetallic materials and composites.
- Radiography is well suited for the inspection of semiconductor devices for detection of cracks, broken wires, unsoldered connections, foreign material and misplaced components. Other NDT methods are limited in their abilities to inspect semiconductor devices.

Applications

- Power Plant Inspection
- Wire Rope Inspection
- Storage Tank Inspection
- Aircraft Inspection
- Jet Engine Inspection
- Rail Line Inspection
- Bridge Inspection
- Pipe Line Inspection
- **Pressure Vessel Inspection**

Pressure Vessels

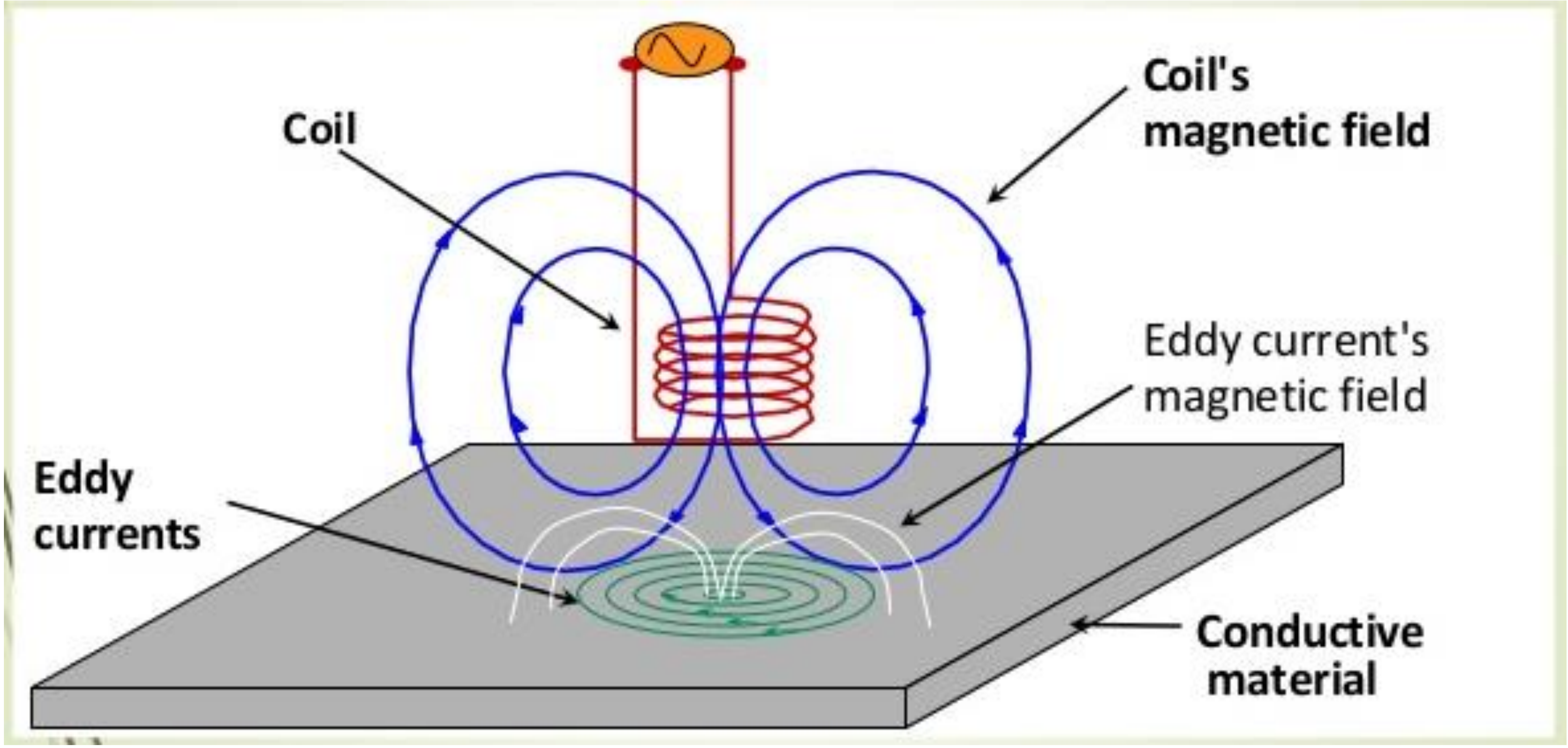
NDT Method Used : Radiography

Advantages and disadvantages of radiography testing

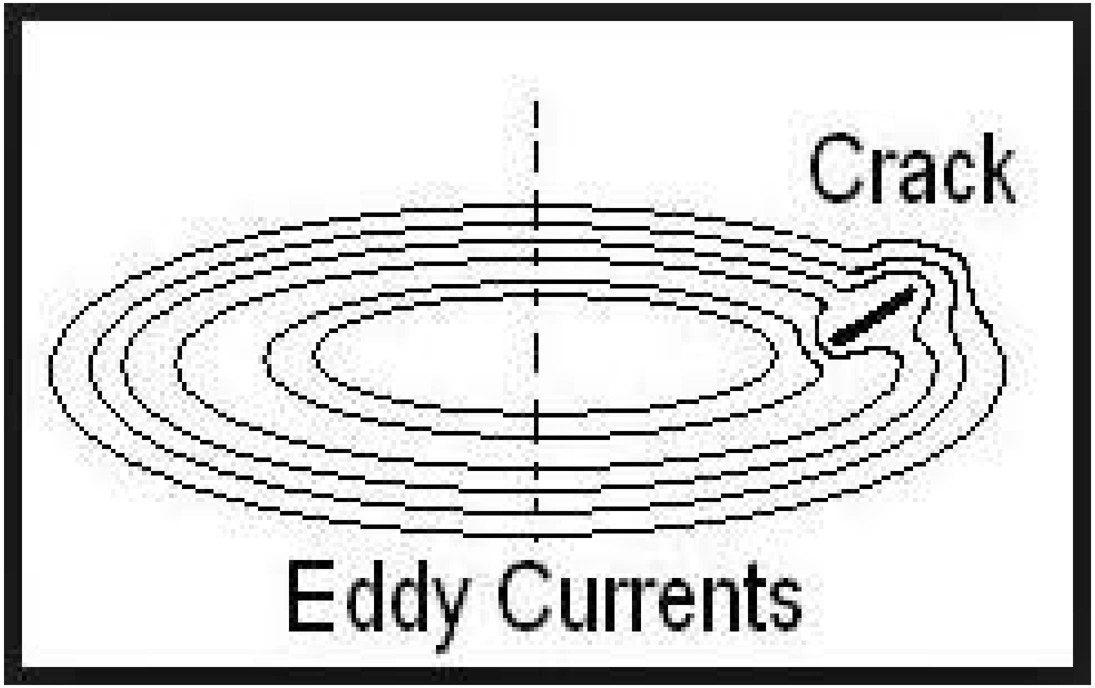
Advantages	Disadvantages
Can be used to inspect virtually all materials.	Extensive operator training and skill required.
Detects surface and subsurface defects.	Depth of Discontinuity not Indicated
Permanent Test Report can be Obtained	Access to both sides of the structure is usually required.
Ability to inspect complex shapes, Hidden areas and multi-layered structures without disassembly.	Orientation of the radiation beam to non-volumetric defects is critical.
Minimum part preparation is required.	Relatively expensive equipment and investment is required.
Technique standardized and Reference standards available	Possible radiation hazard for personnel.

MODULE 6
Eddy Current Testing

Eddy Current Testing (ECT)

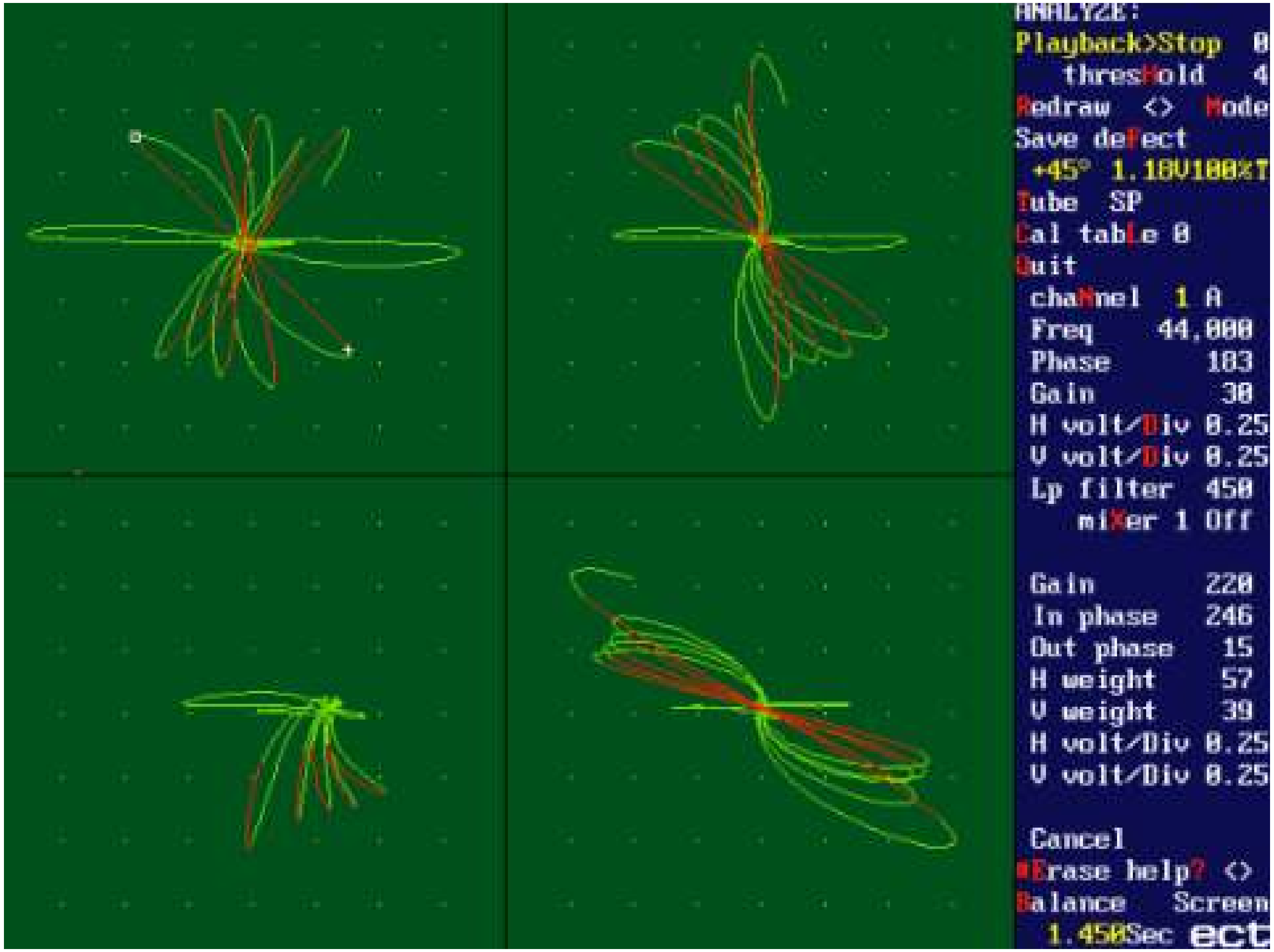


Eddy Current Testing (ECT)



ECT

ECT Results


ANALYZE:
Playback>Stop 0
threshold 4
Redraw <> Mode
Save defect
+45° 1.18V100%T
Tube SP
Cal table 0
Quit
channel 1 A
Freq 44,000
Phase 183
Gain 30
H volt/Div 0.25
V volt/Div 0.25
Lp filter 450
mixer 1 Off
Gain 220
In phase 246
Out phase 15
H weight 57
V weight 39
H volt/Div 0.25
V volt/Div 0.25
Cancel
Erase help? <>
Balance Screen
1.450Sec ect

Eddy Current

- **Definition**
- Eddy current is defined as oscillating electrical currents induced in a conductive material by an alternating magnetic field, due to electro magnetic induction.

Eddy Current Testing – Working Principle

- In ECT, an AC of frequency 1 kHz – 2 kHz is made to flow in a coil which in turn, produces an alternating magnetic field around it.
- Coil when kept close to the conducting metallic test specimen, induces an eddy current flow in the material due to electro magnetic induction.
- Eddy current generated are parallel to the coil winding.

Eddy Current Testing – Working Principle

- Eddy current in turn generates an alternating magnetic field, which may be detected as a voltage across a secondary coil
- When a flaw is introduced, the eddy currents are disrupted
- These disruptions are detected by sensors and displayed through display systems.

Physics aspects of ECT

1. **Conductivity**

- Eddy current will be induced in conductive materials only.
- Conductivity is the measure of how easily the current can flow through a material
- Conductivity of a material is affected by

1. Chemical composition of the specimen
2. Heat treatment process applied
3. Working temperature

Physics aspects of ECT

2. Permeability

- Magnetic permeability is the ratio of magnetic flux density to the magnetizing force of the coil

Physics aspects of ECT

3. Resistivity

- Resistivity is the resistance offered by a material against electrical current to pass through it.
- Increased resistivity of a material converts electrical energy into heat, light or other forms of energy.

Physics aspects of ECT

4. Inductance

- **Self inductance** is the property of a circuit where by a change in current causes a change in voltage in the same circuit.
- **Mutual inductance** happens when one circuit induces current flow in a near by second coil.

Physics aspects of ECT

5. Inductive Reactance

- Induced current which works against the primary current results in a reduction of current flow in the circuit.
- The reduction of current flow in a circuit as a result of induction is called inductive reactance.

Physics aspects of ECT

6. Impedance

- Impedance is the total opposition that a circuit presents to AC
- Impedance consists of Resistance (**R**), Inductive reactance (X_L) and Capacitive reactance (X_C)

Fill / Field Factor

- Fill factor is used to measure how well the coil fills the test piece.

$$\text{Fill factor} = \Phi^2_{coil} / \Phi^2_{test\ piece}$$

where Diameter test piece is the test piece diameter and Diameter coil is the diameter of the coil probe, assuming that both diameters are measured in the same units.

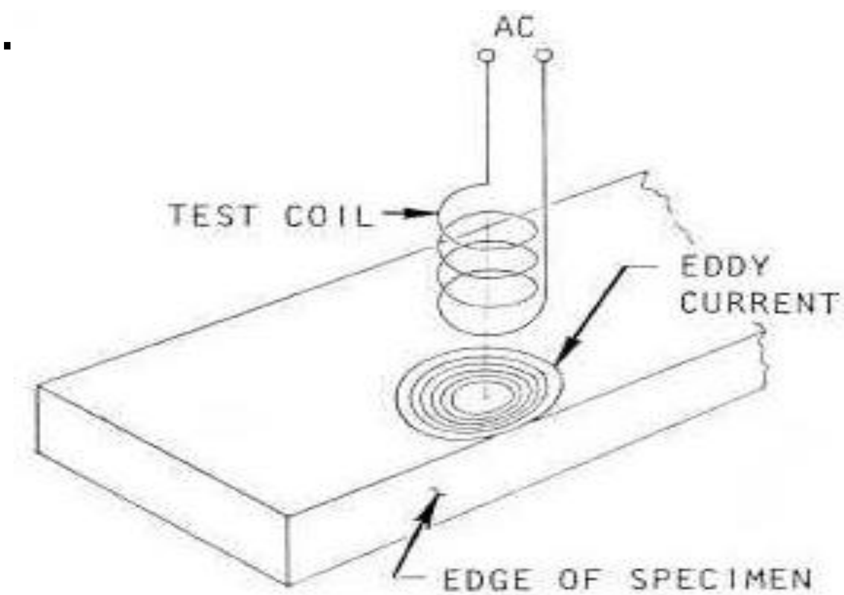
- The coil wires should be as close as possible to the test piece, in order to have greater response to cracks
- Fill factor should be as near as unity.

Lift off effect

- The distance between coil and the test surface is called lift off.
- Lift off has significant effect on sensitivity of ECT
- The closer the lift off, the more denser will be the eddy current generated.

Edge effect

- Edge effect is the phenomenon that occurs when an inspection coil is at the end of the test piece
- At that instance, eddy current flow is distorted as current cannot flow at the edge
- Effect can be avoided by placing a balancing probe near to the edge.

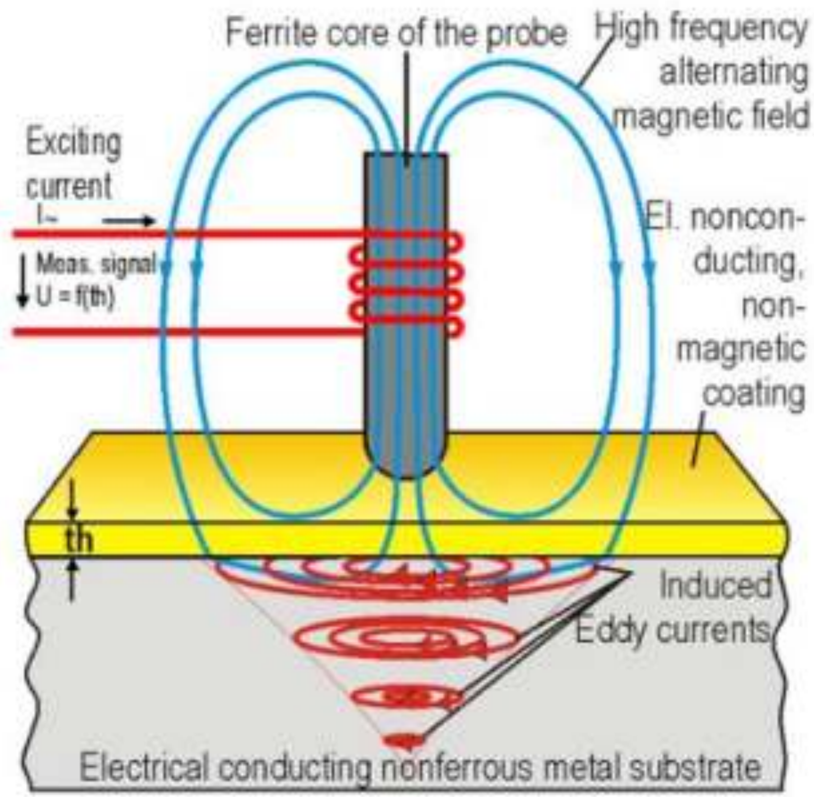


End effect

- End effect is defined as the disturbance of magnetic field, eddy current distribution and impedance when the coil is placed near a change in geometry.

Depth of penetration

- Eddy current concentrates near the surface of test piece and strength decreases with distance from coil increases.
- The phenomenon by which eddy current density decreases with increase in depth is known as **skin effect**
- **Standard depth of penetration or skin depth** is the distance from surface of the specimen, where the eddy current has reduced to **37%** of its surface value.



Eddy current concentrates near the surface and strength decreases as distance from coil increases.

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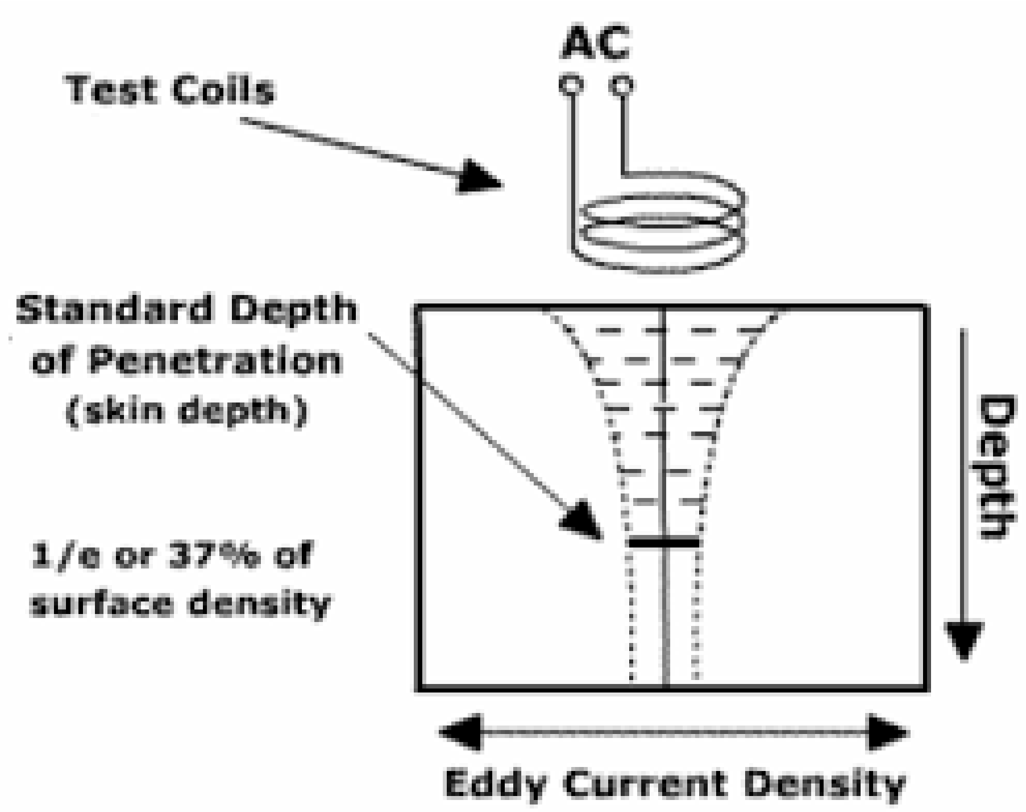
Standard depth of penetration



Frequency & depth of penetration

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

- δ = Standard depth of penetration (mm)
- σ = Conductivity
- μ = Relative permeability
- f = Test frequency (Hz)

As frequency increases, depth of penetration decreases

Applications of ECT

1. Detection of defects

- Defects/ discontinuities are detected when they disrupt the path of eddy currents and weaken their strength.
- High frequency AC is used for checking surface flaws
- Low frequency AC is used for attaining increased depth of penetration for inspecting sub surface flaws.

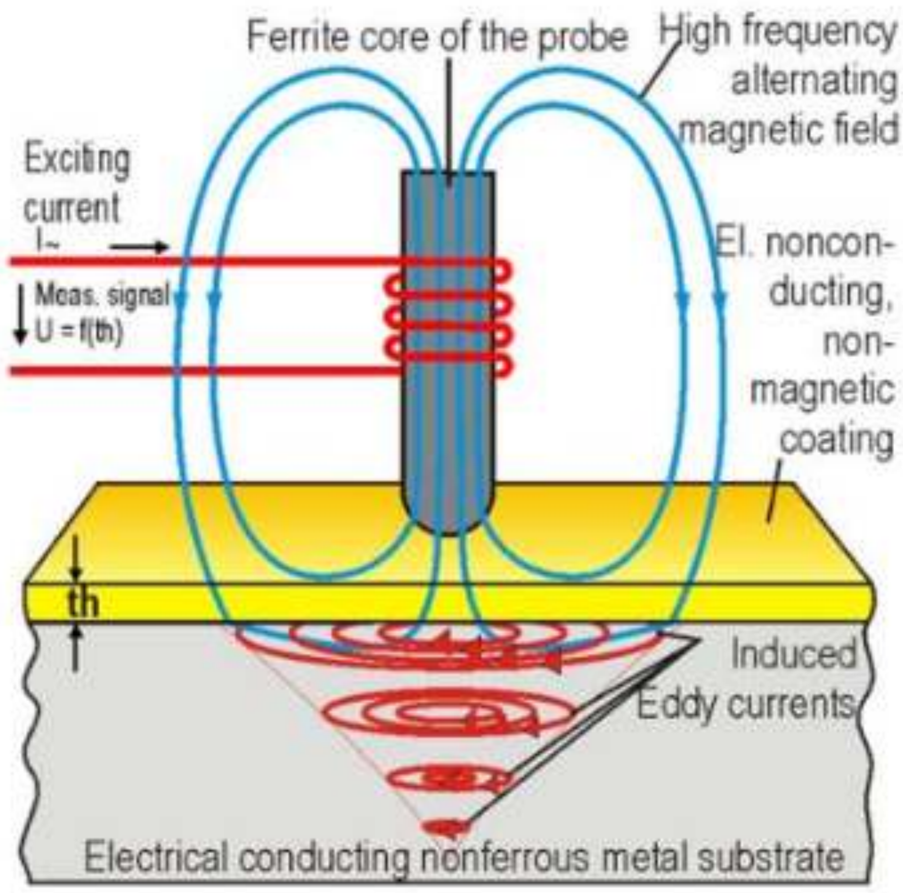
Applications of ECT

2. Conductivity Measurement

- As the conductivity of the test material increases, resistant loss will be less and inductive reactance changes will be greater.
- This intensifies the eddy current generated.
- Intensity of eddy current generated is directly related to conductivity of the specimen.

Applications of ECT

3. Coating thickness measurement



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Applications of ECT

3. Coating thickness measurement

- Non conducting coating increases the lift off distance between eddy current probe and conducting base, which weakens the strength of eddy current generated
- This reduction in strength is measured, which is closely related to coating thickness.

Applications of ECT

4. Thickness measurement of specimens

- ECT are used to measure the thickness of hot sheets, strips and foils in rolling mills.
- Also used to measure the sheet metal thickness of aircrafts and marine vessels.
- During the test, reduction in eddy current strength is measured, which is closely related to specimen thickness.

Advantages of ECT

- Sensitive to small cracks and other defects
- Detects surface and near surface defects
- Inspection gives immediate results
- Equipment is very portable
- Method can be used for much more than flaw detection
- Minimum part preparation is required
- Test probe does not need to contact the part
- Inspects complex shapes and sizes of conductive materials

Limitations of ECT

- Only conductive materials can be inspected
- Surface must be accessible to the probe
- Skill and training required is more extensive than other techniques
- Surface finish and and roughness may interfere
- Reference standards needed for setup
- Depth of penetration is limited
- Flaws such as delaminations that lie parallel to the probe coil winding and probe scan direction are undetectable

Thank You...

All The Best...