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ANGUCHETTYPALAYAM, PANRUTI – 607 106.

OML351 INTRODUCTION TO NON-DESTRUCTIVE TESTING

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DEPARTMENT OF MECHANICAL ENGINEERING

OML351 INTRODUCTION TO NON-DESTRUCTIVE TESTING

UNIT I INTRODUCTION TO NDT & VISUAL TESTING

Concepts of Non-destructive testing-relative merits and limitations-NDT Versus mechanical testing, Fundamentals of Visual Testing – vision, lighting, material attributes, environmental factors, visual perception, direct and indirect methods – mirrors, magnifiers, boroscopes and fibroscopes – light sources and special lighting.

PART - A (2 MARKS)

1. **Give the Importance of using NDT methods? [AM2018]**

NDT ensures the quality, safety, and reliability of the material/design. By Non-destructive Testing, any damage to the asset can be detected beforehand, thus preventing any severe damage. NDT allows us to minimise any environmental hazards arising from a defect.

2. **List out the limitations of NDT? [AM2018]**

Challenges and Limitations of NDT in Failure Analysis:

1 Detection Limits: NDT may miss very small or deeply embedded defects.
2 Interpretation Skills: Requires highly skilled technicians to accurately interpret results.
3 Equipment Sensitivity: Sensitive to environmental conditions and equipment calibration.

3. **When the non-destructive methods are used? [AM2019]**

Nondestructive testing methods are routinely applied in industries where a failure of a component would cause significant hazard or economic loss, such as in transportation, pressure vessels, building structures, piping, and hoisting equipment

4. **Distinguish between destructive and non-destructive testing. [AM2019]**

The difference between destructive and non-destructive testing. Destructive testing is conducted by damaging the specimen that is being tested. In contrast, during non-destructive testing (NDT), the tested item does not suffer any physical damage and can be used in active operation after the testing.

5. **List out the service condition that leads to failure of a material? [AM2017]**

- Reasons for failure include:
- Corrosion.
- Erosion.
- Fatigue.
- Stress corrosion cracking.
- Cavitation.
- Galling.
- Fretting.

6. **Name two of the technique methods that can be detect internal defects. [AM2017]**
Two techniques for detecting internal defects are ultrasonic testing and radiographic testing:
Ultrasonic testing
A common non-destructive testing (NDT) method that detects internal defects in welds and structures. It works by sending a signal from one surface and receiving it on the other side. A coupling agent is applied to the contact area. From one surface and receiving it on the other side. A coupling agent is applied to the contact area.

7. **List the various manufacturing defects and service defects[ND2018]**
Manufacturing defects include:
- Using the wrong materials when constructing a product, including screws, bolts, and fasteners.
- Erroneously assembling materials and parts.
- Incorrectly installing wires and circuitry.
- Using harmful chemicals during the production process.

8. **What are the physical characteristics that can be determined by NDT [ND2018]**
Manufacturing defects
These are errors that occur during production and can include issues like dimensional inaccuracies, surface imperfections, and assembly errors. Manufacturing defects can lead to safety concerns, costly recalls, and loss of reputation.

9. **List any four applications of NDT methods. [ND2021]**
- Aerospace: NDT is used to test castings.
- Automotive: NDT is used to test the durability of piston heads.
- Manufacturing: NDT is used to test the quality of components before they are put into production.
- Medical devices: NDT is used to test the durability and composition of stents.

10. **What are the objectives of non-destructive testing? [ND2021]**
The purpose of NDT is to inspect a component in a safe, reliable, and cost effective manner without causing damage to the equipment or shutting down plant operations.

11. **What is NDT? [ND2017]**
NDT stands for Non-Destructive Testing, which is a group of processes that analyze a material, structure, or component without damaging it. NDT is used to evaluate the quality and structural integrity of a product

12. **What are the applications of visual inspection method? [ND2017]**
Visual inspection is a common, inexpensive, and quick way to detect surface-level defects on objects. It's used in many industries.

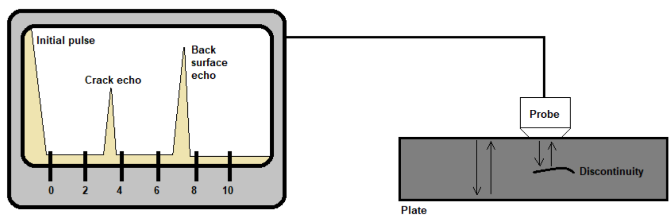
PART - B & C (13MARKS)

1. **Describe the Testing Methods in detail for material characterization.**

Material characterization is essential for understanding the properties and performance of materials used in various applications. Non-Destructive Testing (NDT) methods play a crucial role in this process, as they allow for the evaluation of materials without damaging them. Below are detailed descriptions of the commonly used NDT methods for material characterization:

1. Ultrasonic Testing (UT)

Principle: Ultrasonic testing uses high-frequency sound waves to detect internal flaws, measure thickness, and characterize material properties. A transducer sends ultrasonic waves into the material, and any reflections (from flaws or boundaries) are detected and analyzed.



Applications:

- **Thickness Measurement**: UT is widely used for measuring the thickness of metal plates, pipes, and other materials to detect corrosion or erosion.
- **Flaw Detection**: Cracks, voids, and inclusions can be identified by the reflection of sound waves.
- **Elastic Modulus Measurement**: The speed of sound through a material can provide information about its stiffness or elastic properties.

Advantages:

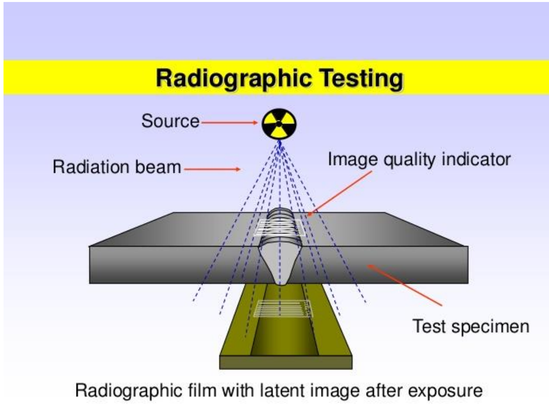
- Can penetrate deep into materials.
- High sensitivity for detecting small flaws.
- Provides detailed information about the material's internal structure.

Limitations:

- Requires a coupling medium (e.g., gel or water).
- May not work well with coarse-grained materials like cast iron.

2. Radiographic Testing (RT)

Principle: Radiographic testing uses X-rays or gamma rays to capture images of the internal structure of a material. The radiation passes through the material and is captured on a detector or film. Differences in material density cause variations in the absorption of the radiation, revealing defects or inconsistencies.



Applications:

- **Detecting Internal Defects**: RT is commonly used to detect voids, inclusions, and cracks inside materials.
- **Weld Inspection**: It is often used to inspect the integrity of welds in pipelines, pressure vessels, and structural components.
- **Composite Inspection**: Used to detect delaminations and inclusions in composite materials.

Advantages:

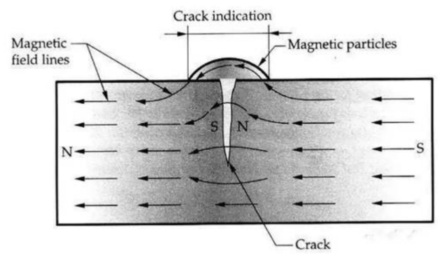
- Provides a permanent record of the test.
- Can detect internal defects in thick materials.
- Useful for complex geometries.

Limitations:

- Requires protection from radiation exposure.
- Relatively expensive and requires sophisticated equipment.
- Detection of small defects may be challenging.

3. Magnetic Particle Testing (MT)

Principle: Magnetic particle testing involves magnetizing a ferromagnetic material and applying ferrous particles to its surface. If there are any surface or near-surface defects (such as cracks), the magnetic field will be distorted, and the particles will gather around the defect, making it visible.



Applications:

- **Surface Crack Detection**: Primarily used for detecting surface and near-surface cracks in ferromagnetic materials.
- **Weld Inspection**: Effective for inspecting welds, especially in steel structures.

Advantages:

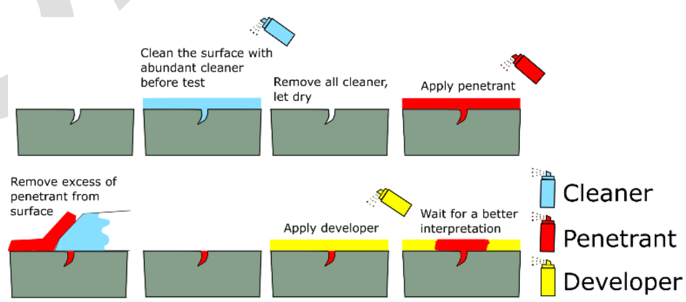
- Simple and cost-effective.
- Sensitive to both surface and shallow subsurface defects.

Limitations:

- Only applicable to ferromagnetic materials (e.g., iron, steel).
- Not suitable for detecting deep internal defects.

4. Liquid Penetrant Testing (PT)

Principle: Liquid penetrant testing involves applying a liquid dye to the surface of a material. The dye seeps into any surface-breaking defects, and after a developer is applied, the dye is drawn out to reveal the defects.



Applications:

- **Surface Defect Detection**: PT is used to detect surface-breaking cracks, porosity, and other flaws in non-porous materials.

- **Material Types**: It can be used on metals, ceramics, and some polymers.

Advantages:

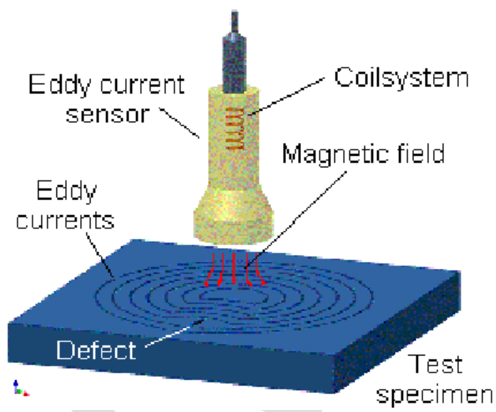
- Easy to perform and inexpensive.
- Can be used on a wide range of materials.

Limitations:

- Only detects surface-breaking defects.
- Requires careful surface preparation and cleaning.

5. Eddy Current Testing (ECT)

Principle: Eddy current testing uses electromagnetic induction to detect defects in conductive materials. A coil carrying an alternating current is placed near the material, inducing eddy currents in the material. Discontinuities, such as cracks, disrupt the flow of these currents and are detected as changes in the impedance of the coil.



Applications:

- **Surface Crack Detection**: Primarily used to detect surface and near-surface defects in metals.
- **Material Thickness Measurement**: Can be used to measure the thickness of non-ferrous materials like aluminum.
- **Corrosion Detection**: Effective for detecting corrosion in conductive materials.

Advantages:

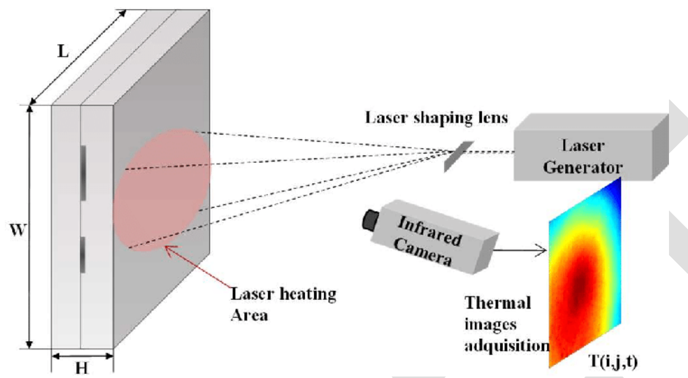
- High sensitivity to small surface defects.
- Can be used on coated materials.
- No need for direct contact with the material.

Limitations:

- Only applicable to conductive materials.
- Limited penetration depth.

6. Thermography (Infrared Testing)

Principle: Thermography detects infrared radiation emitted by an object to measure its temperature distribution. Changes in temperature patterns can reveal hidden defects, such as delaminations or voids, which affect heat flow through the material.



Applications:

- **Composite Inspection**: Used to detect delaminations, voids, and other defects in composite materials.
- **Corrosion Detection**: Effective in detecting corrosion under insulation or surface coatings.
- **Electrical Inspections**: Commonly used to detect overheating in electrical systems.

Advantages:

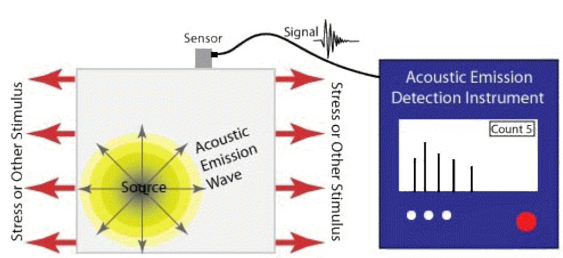
- Non-contact and can be performed from a distance.
- Provides full-field inspection over large areas.

Limitations:

- Limited to surface and near-surface defects.
- Requires calibration and careful interpretation of results.

7. Acoustic Emission Testing (AET)

Principle: Acoustic emission testing involves detecting high-frequency sound waves emitted by a material when it is subjected to stress. The sound waves are generated by the rapid release of energy from defects, such as crack growth or fiber breakage in composites.



Applications:

- **Real-Time Monitoring**: Used for real-time monitoring of structures under load, such as bridges, pressure vessels, and pipelines.
- **Crack Detection**: Detects crack initiation and growth in metals and composites.

Advantages:

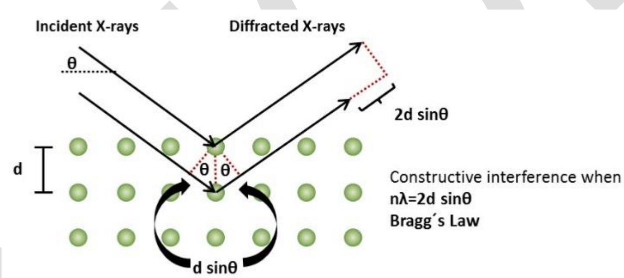
- Can monitor the entire structure in real-time.
- Sensitive to dynamic processes, such as crack growth.

Limitations:

- Requires specialized equipment and expertise.
- Difficult to locate the exact position of the defect.

8. X-ray Diffraction (XRD)

Principle: X-ray diffraction is used to study the crystalline structure of materials by analyzing the pattern of X-rays scattered by the atomic planes in a material. It can provide information about phase composition, crystal structure, and residual stresses.



Applications:

- **Phase Identification**: Used to identify the phases present in a material, such as different types of steel or alloys.
- **Residual Stress Measurement**: Can measure the residual stresses in materials after manufacturing processes like welding or forming.

Advantages:

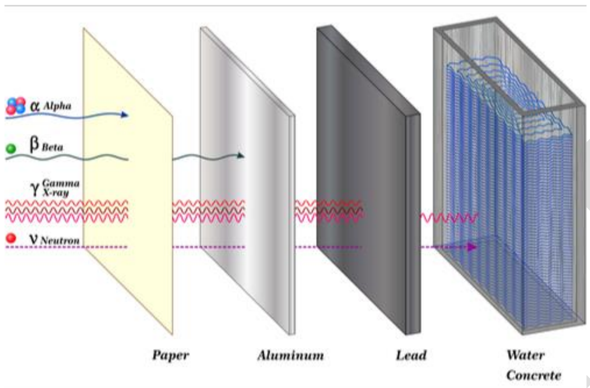
- Highly precise in determining crystallographic information.
- Non-destructive and accurate for surface and near-surface analysis.

Limitations:

- Limited penetration depth.
- Requires careful sample preparation and analysis.

9. Neutron Radiography

Principle: Neutron radiography is similar to X-ray radiography but uses neutrons instead of X-rays. Neutrons interact differently with materials, making them particularly useful for inspecting materials that X-rays cannot penetrate effectively, such as hydrogen-containing substances and certain metals.



Applications:

- **Hydrogen Detection**: Useful for detecting hydrogen embrittlement in metals.
- **Composite Materials**: Can detect water intrusion or voids in composite materials.

Advantages:

- Provides unique insights into certain materials that are opaque to X-rays.

Limitations:

- Requires a neutron source, which can be expensive and complex to operate.

2. **Explain the various optical aids in visual inspection.**

Visual inspection is one of the most fundamental and widely used non-destructive testing (NDT) methods. It relies on the human eye to detect surface defects, such as cracks, corrosion, misalignment, and other anomalies. However, certain defects are too small to be detected by the naked eye or are located in areas that are difficult to access. In these cases, **optical aids** are used to enhance the effectiveness of visual inspection. Below is a detailed explanation of various optical aids used in visual inspection:

1. Magnifying Glasses

- **Principle**: A magnifying glass uses a convex lens to enlarge the appearance of objects, making small surface defects like cracks, pits, or inclusions visible.

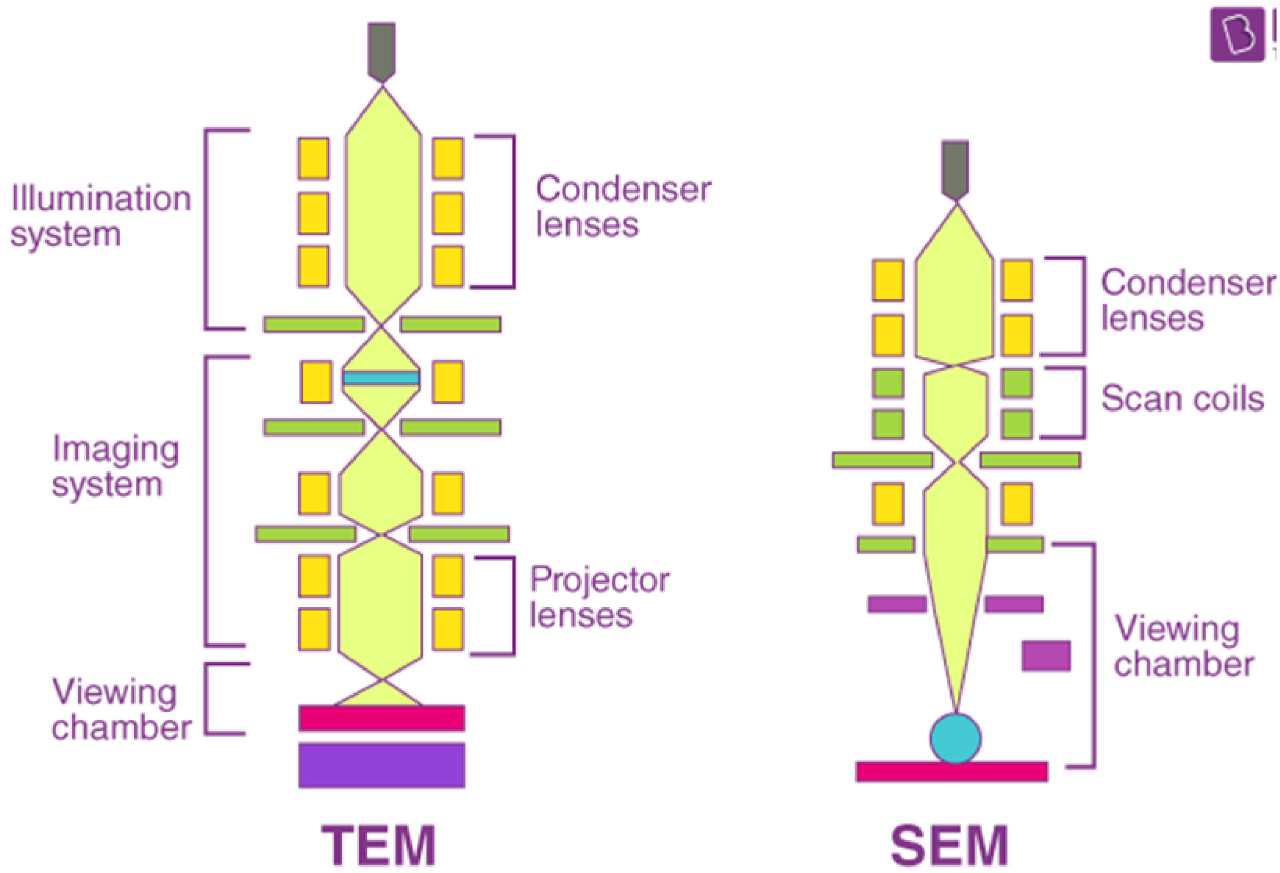
- **Applications**:
  - **Surface Crack Detection**: Commonly used for inspecting small parts, components, or areas where precise visual detail is required.
  - **Weld Inspection**: Frequently used for examining welds to check for small surface cracks or porosity.
- **Advantages**:
  - Simple and inexpensive.
  - Easily portable and can be used in various environments.
- **Limitations**:
  - Limited magnification power (usually up to 10x).
  - Manual operation, dependent on the skill of the inspector.

2. Microscopes

- **Principle**: Microscopes provide high magnification (ranging from 10x to 1000x or more) by using multiple lenses to observe very fine details on the surface of a material.

An electron microscope is defined as the type of microscope in which the source of illumination is the beam of accelerated electrons. It is a special type of microscope with a high resolution of images as the images can be magnified in nanometers.
There are two types of electron microscopes:

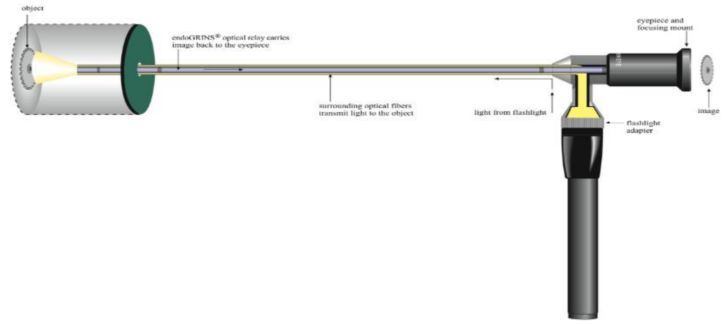
- The transmission electron microscope (TEM)
- The scanning electron microscope (SEM)



- **Types**:
  - **Optical Microscopes**: Use visible light and lenses to magnify small surface details.
  - **Stereo Microscopes**: Provide a three-dimensional view of the surface for more detailed examination.
  - **Digital Microscopes**: Capture high-resolution images that can be analyzed and shared digitally.
- **Applications**:
  - **Micro-Crack Detection**: Useful in detecting very fine cracks or surface irregularities.
  - **Material Analysis**: Used in metallurgy and material science for analyzing microstructures.
  - **Weld and Solder Joint Inspection**: Ideal for high-precision industries like electronics manufacturing.
- **Advantages**:
  - High magnification for detailed surface inspection.
  - Some types (e.g., digital) offer image storage and analysis.
- **Limitations**:
  - Requires stable mounting for high magnifications.
  - Limited to small areas and surface inspections.

3. Borescopes

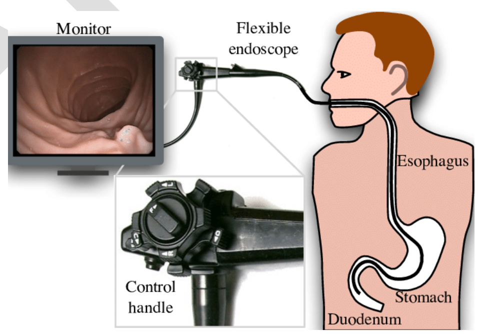
- **Principle**: A borescope is a tube-like optical instrument equipped with a camera or lens at one end and an eyepiece or screen at the other. It allows for visual inspection inside confined spaces, such as pipes, engines, and machinery, where direct line-of-sight inspection is not possible.



- **Types**:
    - **Rigid Borescopes**: Made of a rigid tube, ideal for inspecting straight-line access areas.
    - **Flexible Borescopes (Fiberscopes)**: Use flexible tubing, allowing access to curved or difficult-to-reach areas.
    - **Video Borescopes**: Incorporate a camera at the tip, providing live video feeds to a screen, allowing for easy documentation and sharing of the inspection.
- **Applications**:
    - **Internal Inspection of Engines and Pipelines**: Commonly used in aerospace, automotive, and oil & gas industries to inspect internal components for wear, corrosion, or cracking.
    - **Aviation Maintenance**: Used to inspect turbine blades and other engine components without disassembly.
- **Advantages**:
    - Allows access to otherwise inaccessible areas.
    - Flexible versions can inspect around bends or corners.
    - High-quality images and video for analysis and reporting.
- **Limitations**:
    - Some models can be expensive.
    - Requires training to interpret images accurately.

4. Endoscopes

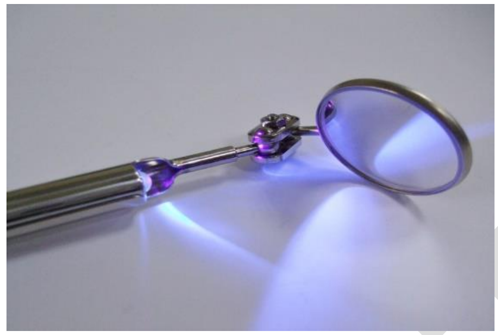
- **Principle**: Similar to borescopes, endoscopes are used to inspect hard-to-reach areas. They are primarily designed for medical applications but are also used in industrial settings for visual inspections.



- **Applications**:
    - **Internal Component Inspection**: Used for inspecting the interior of machinery, pipes, or small cavities that cannot be accessed directly.
    - **Aircraft and Engine Inspection**: Particularly useful in industries like aerospace and automotive for internal part inspections.
- **Advantages**:
    - Provides clear images or video of internal spaces.
    - Highly flexible and can navigate tight bends and curves.
- **Limitations**:
    - Can be expensive.
    - Interpretation of results requires experience.

5. Inspection Mirrors

- **Principle**: Inspection mirrors are simple tools consisting of a mirror attached to an adjustable handle. They allow inspectors to see areas that are otherwise difficult to access, such as the back of components, tight spaces, or overhead structures.



- **Applications**:
  - **Visual Inspection of Hidden Areas**: Used in automotive and machinery maintenance to inspect hidden components.
  - **Building Inspection**: Helps inspect hard-to-reach places like roofs, ceilings, and behind structural components.
- **Advantages**:
  - Inexpensive and easy to use.
  - Portable and versatile for a wide range of applications.
- **Limitations**:
  - No magnification; dependent on the user's vision.
  - Limited to surface inspections.

6. Magnifying Mirrors

- **Principle**: A magnifying mirror combines the benefits of magnification and an angled mirror, enabling the user to inspect small defects in hard-to-reach areas.

- **Applications**:
  - **Precision Inspection in Tight Spaces**: Useful for detailed inspections in areas that are difficult to access directly.
  - **Automotive and Aircraft Maintenance**: Commonly used to check the integrity of parts and components.
- **Advantages**:
  - Provides both magnification and indirect viewing capabilities.
- **Limitations**:
  - Limited magnification power.
  - Requires proper lighting for effective inspection.

7. Illuminated Magnifiers

- **Principle**: These devices combine a magnifying lens with a built-in light source to enhance visibility while inspecting materials or components. They are particularly useful when lighting conditions are poor.

- **Applications**:
    - **Inspection of Electronics and Small Components**: Commonly used in industries like electronics, precision manufacturing, and watchmaking.
    - **Weld and Material Surface Inspection**: Helps identify small surface defects that may not be visible under normal lighting.
- **Advantages**:
    - Provides both magnification and illumination for detailed inspections.
    - Portable and can be used in various lighting conditions.
- **Limitations**:
    - Limited to small areas.
    - Manual operation may lead to user fatigue over time.

8. Cameras with Zoom Lenses

- **Principle**: These cameras have powerful zoom lenses that allow inspectors to magnify images of surfaces or components during visual inspections. They often come with image-capturing capabilities for documentation and further analysis.

- **Applications**:

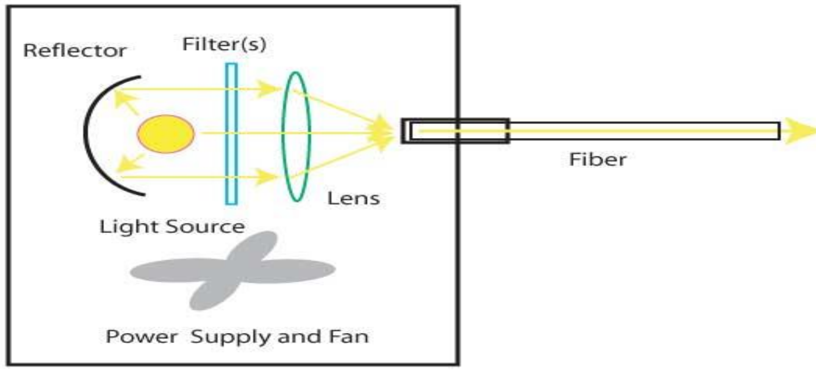
    - **Remote and Distance Inspection**: Commonly used to inspect areas that are either hard to access or require examination from a distance, such as tall structures, bridges, or power lines.
    - **Documentation and Reporting**: Useful for capturing images for later analysis or reporting.
- **Advantages**:
    - High magnification power and image clarity.
    - Provides a permanent record of the inspection.
- **Limitations**:
    - Requires careful setup and operation.
    - More expensive than simpler optical aids.

9. Ring Lights and Portable Lighting

- **Principle**: Portable ring lights or other illumination devices are used in conjunction with visual inspection tools like magnifiers or borescopes. Proper lighting is critical for identifying defects, especially in poorly lit environments.

- **Applications**:
    - **Low-Light Inspections**: Ideal for inspecting areas where natural or ambient lighting is insufficient.
    - **Detailed Surface Inspection**: Used in conjunction with magnifiers or microscopes to enhance surface visibility.
- **Advantages**:
    - Enhances visibility in challenging lighting conditions.
    - Portable and can be positioned as needed.
- **Limitations**:
    - Requires power (battery or mains).
    - Dependent on external tools for inspection.

10. Light Sources and Fiber Optics



- **Principle**: Fiber optic lighting systems use flexible light guides to direct light into dark or hard-to-reach areas. These are often paired with borescopes or endoscopes for internal visual inspections.
- **Applications**:
  - **Internal Cavity Illumination**: Useful in illuminating dark areas such as the inside of machinery, engines, or pipes during visual inspection.
  - **Complex Assembly Inspection**: Common in the aerospace and automotive industries for inspecting intricate assemblies.
- **Advantages**:
  - Provides focused illumination in difficult-to-reach areas.
  - Flexible and can be directed to specific areas.
- **Limitations**:
  - Can be complex to set up and may require specific equipment.

3. Explain the following (i) Application of Visual Inspection (ii) Advantages and Disadvantages of Visual Inspection.

(i) Application of Visual Inspection

Visual Inspection is a non-destructive testing (NDT) technique used to examine surfaces for defects or irregularities, often in industrial and engineering settings. It involves using the human eye, sometimes aided by tools like magnifying glasses, cameras, or drones, to detect issues in materials, structures, or products.

Common applications include:

1. **Manufacturing Quality Control**:
   - Ensures products meet design specifications before they leave the production line.
   - Detects surface defects, such as cracks, corrosion, or misalignments.
2. **Maintenance of Equipment and Infrastructure**:
   - Regular inspection of pipelines, bridges, buildings, aircraft, and machinery to detect wear and tear, cracks, or corrosion.
   - Prevents accidents and equipment failure by identifying potential issues early.
3. **Aerospace and Automotive Industry**:
   - Inspects aircraft components like turbine blades and fuselages for structural integrity.
   - Ensures that automotive parts, such as engines and chassis, are free from defects.
4. **Civil Engineering**:
   - Used to assess the condition of bridges, dams, tunnels, and other infrastructure for cracks, material degradation, and overall stability.
5. **Welding Inspection**:

    - Evaluates welds to check for incomplete penetration, cracks, or other flaws that could compromise strength.
6. **Pipeline Inspection**:
    - Helps identify corrosion, leaks, and other issues in gas or oil pipelines to prevent environmental disasters.

(ii) Advantages and Disadvantages of Visual Inspection

Advantages:

1. **Cost-Effective**:
    - Minimal equipment is needed, making it one of the least expensive NDT methods.
2. **Quick and Simple**:
    - Easy to perform with basic training.
    - Immediate results can be obtained, allowing for quick decisions.
3. **Non-Destructive**:
    - Does not damage the object or material being inspected.
4. **Wide Range of Applications**:
    - Can be applied to a variety of materials, including metals, plastics, composites, and concrete.
5. **Real-Time Feedback**:
    - Provides instant feedback during the inspection process, allowing for immediate corrective actions if defects are found.

Disadvantages:

1. **Limited to Surface Defects**:
    - Only detects surface-level issues; internal defects cannot be identified without other testing methods.
2. **Subjective**:
    - The quality of the inspection depends on the skill and experience of the inspector.
    - Results may vary between different inspectors.
3. **Limited by Accessibility**:
    - Difficult or impossible to inspect areas that are hard to reach or concealed, such as inside pipes or machinery without additional tools.
4. **Lighting Conditions**:
    - Poor lighting can hinder the ability to detect flaws.
5. **Requires Human Presence**:
    - Requires inspectors to be physically present, which may pose safety risks in hazardous environments, though this is mitigated by the use of remote inspection tools in some cases.

4. List the advantages, disadvantages and applications of non-destructive testing. Also discuss

the major factors that must be considered for an effective Non Destructive testing.

Advantages, Disadvantages, and Applications of Non-Destructive Testing (NDT)

Advantages of Non-Destructive Testing (NDT):

1. **Preservation of Material Integrity**:
   - The material or object remains undamaged after testing, allowing it to be used or sold after inspection.
2. **Cost-Effective in the Long Run**:
   - Early detection of defects can prevent costly failures or accidents, reducing the need for expensive repairs or replacements.
3. **Wide Range of Applications**:
   - Can be used on various materials, including metals, ceramics, polymers, and composites, across different industries.
4. **Early Detection of Defects**:
   - Allows for the identification of surface and subsurface defects before they lead to larger failures or accidents.
5. **Ensures Safety and Reliability**:
   - Crucial for maintaining the safety of critical infrastructure and components in industries like aerospace, oil and gas, and civil engineering.
6. **Comprehensive Testing**:
   - NDT methods can detect surface cracks, corrosion, internal defects, and other issues that may not be visible to the naked eye.
7. **Compliance with Standards and Regulations**:
   - Helps ensure that products and materials meet industry standards, regulations, and safety requirements.
8. **Reduces Downtime**:
   - Inspections can often be performed without taking equipment out of service, minimizing downtime.

Disadvantages of Non-Destructive Testing (NDT):

1. **High Initial Costs**:
   - The cost of specialized equipment and skilled personnel can be high, especially for advanced techniques like ultrasonic or radiographic testing.
2. **Requires Skilled Technicians**:
   - Interpreting NDT results requires expertise, and misinterpretation can lead to incorrect conclusions.
3. **Limited Detection Capabilities**:
   - Some methods may only detect certain types of defects, and multiple methods may be required to get a full picture of the material's condition.
4. **Complex Setup for Some Methods**:
   - Techniques like radiography require extensive safety measures and complex setups, which may be time-consuming.
5. **Safety Concerns**:
   - Some methods, such as radiography, expose technicians to potentially harmful radiation, requiring strict safety protocols.
6. **Surface Accessibility**:
   - Some methods may require direct access to the surface of the material, which can be a challenge in certain applications.

Applications of Non-Destructive Testing (NDT):

1. **Aerospace Industry**:
   - Inspection of aircraft components like engines, wings, and fuselages to detect cracks, corrosion, and other defects that could compromise safety.
2. **Oil and Gas Industry**:
   - Monitoring the condition of pipelines, storage tanks, and offshore platforms to detect corrosion, leaks, and mechanical damage.
3. **Automotive Industry**:
   - Ensuring the structural integrity of critical components such as engines, gearboxes, and frames.
4. **Power Generation**:
   - Inspecting turbines, boilers, and nuclear reactor components for cracks, corrosion, and material degradation.
5. **Civil Engineering**:
   - Assessing the structural health of bridges, dams, tunnels, and buildings, identifying issues like cracks, rebar corrosion, or material fatigue.
6. **Manufacturing**:
   - Quality control of welds, castings, and machined parts, ensuring they meet design specifications and are free from defects.
7. **Railway Industry**:
   - Monitoring the condition of rails, axles, and wheels to ensure safe operation and prevent derailments.
8. **Marine Industry**:
   - Inspection of ship hulls, propellers, and other critical components to prevent corrosion and structural failure.

Major Factors to Consider for Effective Non-Destructive Testing (NDT)

1. **Material Type and Condition**:
   - The NDT method selected must be compatible with the material being tested (metal, composite, concrete, etc.).
   - Factors like thickness, conductivity, and the surface condition of the material can affect the effectiveness of the method.
2. **Type of Defect**:
   - The type of defect (surface cracks, internal voids, corrosion) dictates the appropriate NDT technique.
   - For example, **ultrasonic testing** is effective for detecting internal flaws, while **visual inspection** is limited to surface defects.
3. **Accessibility**:
   - Certain areas of the material or structure may be difficult to access.
   - Methods like **remote visual inspection** or **drone-based inspections** may be needed for hard-to-reach locations.
4. **Sensitivity and Accuracy of the Method**:
   - The sensitivity of the NDT method must match the defect size and type expected. For example, **radiography** is often used for detailed imaging of internal defects.
5. **Cost and Availability of Equipment**:
   - The cost of the testing equipment and the budget available should be considered. Some methods, like **magnetic particle inspection**, are relatively inexpensive, while others, like **computed tomography**, can be costly.
6. **Safety Considerations**:
   - Methods involving radiation (e.g., radiographic testing) require strict safety protocols and may not be suitable in certain environments without adequate precautions.
7. **Environmental Conditions**:
   - Factors like temperature, humidity, and lighting can affect the NDT process. Some methods may not work well in extreme temperatures or underwater.

8. **Skill and Experience of the Technician**:
    - NDT requires skilled technicians for accurate interpretation of results. A high level of expertise is necessary to ensure reliability and avoid false positives or negatives.
9. **Compliance with Standards**:
    - NDT methods should meet applicable standards and codes for the industry or material in question (e.g., ASTM, ISO, or ASME standards).
10. **Inspection Frequency**:
    - The frequency of inspections must align with the lifecycle and safety requirements of the asset being tested. Critical components may need more frequent inspections compared to less critical ones.
11. **Data Recording and Analysis**:
    - Effective data recording and analysis are crucial for making informed decisions. Advanced methods often require software for data interpretation and storage.

5. Discuss in detail about the various types of Boroscopes used in Visual Inspection with Neat sketches.

Boroscopes in Visual Inspection

A **boroscope** is a specialized optical device used in non-destructive visual inspection to view areas that are otherwise inaccessible. It consists of a rigid or flexible tube with an eyepiece on one end and a lens or camera on the other, often equipped with light sources to illuminate the inspection area. Boroscopes are widely used in industries like aerospace, automotive, oil & gas, and manufacturing to inspect engines, pipes, turbines, and machinery components without disassembly.

There are several types of boroscopes used in visual inspection, each tailored to specific applications and environments. The two main types are **rigid boroscopes** and **flexible boroscopes**, with variations within these categories, such as **fiberscopes** and **video boroscopes**.

---

1. Rigid Boroscope

A **rigid boroscope** consists of a straight, inflexible tube with an optical lens system. The tube is usually made of stainless steel, and the device is ideal for inspecting straight-line, hard-to-reach areas.

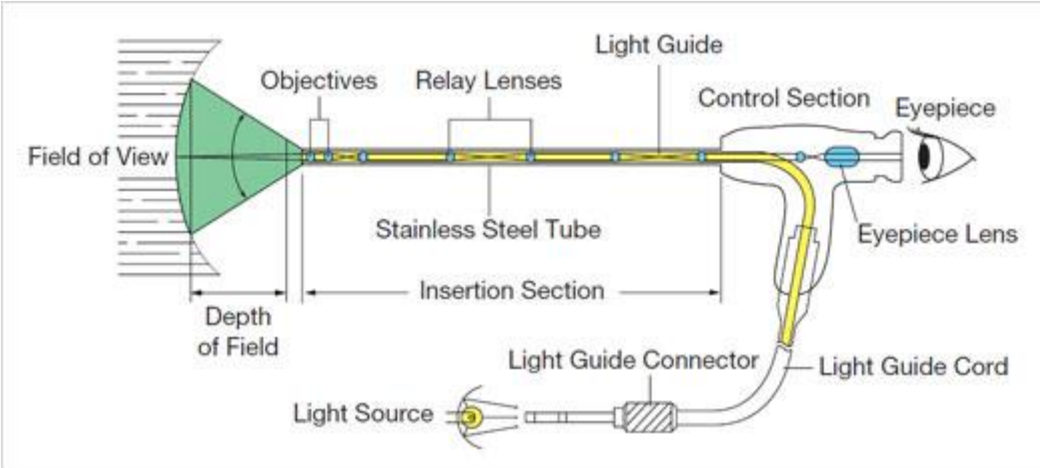
- **Design**: The rigid boroscope has an eyepiece for viewing, a straight rigid tube, and lenses. A light source, either built-in or external, is often connected to illuminate the target.
- **Applications**: Used where the inspection area is easily accessible and straight, such as inspecting internal parts of machines, engines, turbines, and certain industrial components.

Key Features:

- High-quality image clarity.
- Simple design, robust, and cost-effective.
- Limited to inspecting straight areas or paths.

Neat Sketch:

```
Eyepiece -----> (Rigid Tube) -----> Lens -----> (Target Area)
                         |
                  Light Source
```



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2. Flexible Boroscope (Fiberscope)

A **flexible boroscope**, also called a **fiberscope**, consists of a flexible tube containing fiber optic bundles to transmit the image from the inspection area to the eyepiece. This allows it to bend and curve through tight and complex spaces.

- **Design**: Flexible boroscopes are equipped with a bundle of optical fibers, which can transmit images even when the tube is bent. Some models allow for articulation, which gives the user control over the bending of the tip.
- **Applications**: Ideal for inspecting complex internal structures like piping systems, aircraft engines, and areas that are difficult to access with a rigid boroscope.

Key Features:

- Can bend and navigate around curves or obstacles.
- Provides access to areas that rigid boroscopes cannot reach.
- Generally lower image quality compared to rigid boroscopes due to fiber optic distortion.

Neat Sketch:

```
Eyepiece -----> (Flexible Tube) -----> Fiberscope Lenses -----> (Target Area)
                                |
                          Light Source
```

3. Video Boroscope

A **video boroscope** integrates a small camera at the distal end of the probe instead of using fiber optics to relay the image. The camera sends live video to a display screen, allowing for detailed real-time inspection.

- **Design**: A video boroscope consists of a flexible or rigid probe, a small camera at the tip, and a display monitor. Most video boroscopes come with articulation controls to maneuver the camera tip.
- **Applications**: Widely used in industrial maintenance, automotive inspection, aerospace industries, and in the inspection of turbines, pipelines, and engines.

Key Features:

- High-quality image resolution.
- Real-time video feed on a monitor.
- Capable of capturing images and recording videos for further analysis.
- Flexible articulation allows the camera to navigate through complex structures.

Neat Sketch:

```
Display Screen <--- (Video Cable) <--- (Articulated Probe) <--Camera --> Target Area)
                                                 |
                                            Light Source
```

---

4. Semi-Rigid Boroscope

A **semi-rigid boroscope** combines the flexibility of a flexible boroscope with the stiffness of a rigid one. The tube can bend to a limited extent, but retains some rigidity, making it ideal for applications where partial flexibility is needed.

- **Design**: The tube is somewhat flexible but maintains its shape to some extent. It can be bent manually but will not navigate through tight curves as easily as a fiberscope.
- **Applications**: Often used in automotive or aerospace industries for inspecting moderately curved areas like ducts, pipes, or engines.

Key Features:

- More versatile than rigid boroscopes but less flexible than fiberscopes.
- Higher image quality than fiberscopes, but with limited maneuverability.

Neat Sketch:

```
Eyepiece -----> (Semi-Rigid Tube) -----> Lens -----> (Target Area)
                          |
                   Light Source
```

---

5. Articulating Boroscope

An **articulating boroscope** is a flexible boroscope equipped with a mechanism that allows the operator to control the direction of the tip. This feature provides better access and visualization of complex internal structures.

- **Design**: The tip of the probe can be controlled using a mechanical lever or electronic system, allowing for precise directionality.
- **Applications**: Useful in highly complex environments like jet engines or intricate machinery where the user needs to inspect various angles and orientations.

Key Features:

- Precision control over the tip direction.
- Provides a greater degree of inspection versatility.
- Typically higher in cost due to the added articulation feature.

Neat Sketch:

```
Control Handle <---- (Flexible Tube) <---- Articulated Tip ----> (Target Area)
                              |
                        Light Source
```

Summary Table of Boroscope Types:

Type	Flexibility	Image Quality	Typical Applications
Rigid Boroscope	No flexibility	High	Inspection of straight components (engines, turbines, etc.)
Flexible Boroscope	Fully flexible	Medium	Piping systems, complex structures, aerospace engines
Video Boroscope	Fully flexible	High (camera-based)	Real-time video inspections in turbines, engines, manufacturing
Semi-Rigid Boroscope	Semi-flexible	Medium-High	Moderately curved systems in automotive and industrial applications
Articulating Boroscope	Fully flexible, directional	Medium-High	Complex machinery, jet engines, areas requiring multiple viewpoints

6. Differentiate between Destructive and Non Destructive testing.

Destructive Testing (DT) vs. Non-Destructive Testing (NDT)

Destructive Testing (DT) and Non-Destructive Testing (NDT) are two widely used methods to evaluate the properties and integrity of materials, components, or structures. The key difference between these methods is whether the material is damaged or preserved after the test.

Criteria	Destructive Testing (DT)	Non-Destructive Testing (NDT)
Definition	Involves testing a material or component to the point of failure to understand its performance under stress, load, or other conditions.	Involves examining a material or component without causing damage or altering its future usability.
Purpose	Determines the material's ultimate strength, durability, fracture toughness, and limits. It ensures the material can withstand operational stresses before failure.	Identifies defects, flaws, and irregularities in materials or structures without damaging them. This ensures the material is fit for use without compromising its integrity.
Effect on the Material	Permanently damages or destroys the test specimen.	Leaves the material intact and reusable after the test.
Common Methods	- Tensile Testing - Compression Testing - Impact Testing (Charpy, Izod) - Hardness Testing - Fatigue Testing - Bend and Fracture Testing	- Visual Inspection - Ultrasonic Testing - Radiography (X-ray) - Eddy Current Testing - Magnetic Particle Testing - Liquid Penetrant Testing - Acoustic Emission Testing
Testing Conditions	Tests are usually performed under extreme conditions to push the material to failure, such as high stress, strain, or impact.	Tests are usually performed under normal or controlled conditions that replicate service environments to detect defects without pushing the material to failure.
Sample Requirement	Requires a sample piece or entire product to be sacrificed for testing. In some cases, multiple samples may be needed.	Can be performed on the entire component or structure without the need for cutting or altering the material.
Cost	Often more expensive in terms of material costs, as the tested component or sample is destroyed and cannot be used afterward.	Generally more cost-effective since the tested material remains usable. However, sophisticated NDT methods may require expensive equipment and skilled operators.
Time Taken	Typically takes longer as it involves preparing samples, performing tests, and analyzing post-failure data.	Usually quicker, as many tests are performed in real-time without the need for destruction or post-test analysis.
Accuracy of Results	Provides precise quantitative data regarding the material's ultimate limits, like tensile strength, impact resistance, and failure points.	Provides qualitative or quantitative data on surface and subsurface defects but may not determine the material's ultimate strength or failure limits.

Criteria	Destructive Testing (DT)	Non-Destructive Testing (NDT)
Skill and Training	Requires skilled technicians to conduct the tests and analyze failure results, but generally has less complexity in test execution compared to NDT.	Requires skilled personnel to operate advanced equipment and interpret results, especially for complex techniques like ultrasonic or radiographic testing.
Applicability	Often used for testing prototype designs, research, and material selection where failure data is critical. Not ideal for finished products.	Ideal for inspecting finished products, in-service components, or critical infrastructure where damaging the material is unacceptable.
Common Industries	- Material Science - Research and Development (R&D) - Construction - Aerospace (for material property analysis) - Automotive	- Aerospace - Automotive - Oil & Gas - Power Generation - Manufacturing - Civil Engineering (for infrastructure inspections)
Failure Information	Provides detailed information about the failure modes of the material or component, such as fracture toughness, fatigue, or crack propagation.	Provides information on the presence of defects (cracks, voids, corrosion) but not on failure limits or fracture toughness.
Regulatory Impact	Not typically used in regulatory certification unless stress limits and performance need validation.	Widely used for regulatory compliance in safety-critical industries, as it ensures components are defect-free without compromising their usability.

Key Differences

1. **Impact on Material**:
   - **DT**: Destroys the material during testing.
   - **NDT**: Leaves the material intact.
2. **Purpose**:
   - **DT**: Focuses on finding the ultimate strength and failure points.
   - **NDT**: Focuses on identifying defects without causing damage.
3. **Sample Requirement**:
   - **DT**: Requires the sample to be sacrificed.
   - **NDT**: Does not alter the test sample.
4. **Cost Implication**:
   - **DT**: Higher costs due to material destruction.
   - **NDT**: More cost-effective since the material remains usable.
5. **Testing Process**:
   - **DT**: Usually requires more time to prepare, test, and analyze.
   - **NDT**: Provides quicker results, often in real-time.

UNIT II LIQUID PENETRANT & MAGNETIC PARTICLE TESTING

Liquid Penetrant Inspection: principle, applications, advantages and limitations, dyes, developers and cleaners, Methods & Interpretation. Magnetic Particle Inspection: Principles, applications, magnetization methods, magnetic particles, Testing Procedure, demagnetization, advantages and limitations, – Interpretation and evaluation of test indications.

PART - A (2 MARKS)

1. **What are the principle methods available in penetrant Tests? [AM2018]**
   The basic principle of liquid penetrant testing (PT) is capillary action, which allows the penetrant to enter in the opening of the defect, remain there when the liquid is removed from the material surface, and then re-emerge on the surface on application of a developer, which has a capillary action

2. **Give the merits and demerits of Dry Developers. [AM2018]**

ADVANTAGES

1. Inspection with this method is of low cost (materials and associated equipment are relatively inexpensive)
2. It is possible to do rapid inspection of large areas and volumes.
3. It has high sensitivity (small discontinuities can be detected).
4. This method is suitable for parts with complex shapes.
5. Equipment is highly portable (materials are available in aerosol spray cans).
6. Various types of materials can be inspected such as metallic and non-metallic, magnetic and nonmagnetic, and conductive and non-conductive materials may be inspected.
7. Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.

DISADVANTAGES

1. With this method, only surface breaking defects can be detected.
2. It is possible to inspect only materials with relatively nonporous surface.
3. It is necessary to pre-clean the material since contaminants can mask defects.
4. Metal smearing from machining, grinding, and grit or vapor blasting must be removed.
5. Direct access to the surface being inspected is necessary.
6. Surface finish and roughness can affect inspection sensitivity.
7. It is necessary to perform and control multiple process operations.
8. Post cleaning of acceptable parts or materials is required.
9. This method involves chemical handling and its proper disposal.

3. **Advantages and limitations of LPT. [AM2019]**
   Liquid penetrant testing has the following advantages:
   - Works on complicated geometric shapes.
   - LPI materials are compact.
   - Sensitive to small surface interruptions.

- Few material limitations such as—works on non-metallic, metallic, non-magnetic, magnetic, non-conductive and conductive materials.

Liquid penetrant testing has the following disadvantages:

- Extensive, time-taking pre-cleaning critical—surface contaminants can mask defects.
- Sensitive to surface-breaking defects only.
- Direct connection to the surface under test necessary.
- Works on relatively non-porous surface materials only.
- No depth sizing.

4. **For which type of materials penetrant testing is not recommended? [AM2019]**

Penetrants can be used to inspect ferrous and nonferrous metals. Penetrant inspection will find discontinuities open to the surface on ferrous and nonferrous metals. Penetrant testing should not be done on porous surfaces, as the pores will act as discontinuities to trap penetrant and prevent accurate inspection.

5. **What is the size of the magnetic particles on the test performance in MPT? [AM2017]**

The particles are typically 10 µm (0.0004 inch) and smaller and the synthetic iron oxides have particle diameters around 0.1 µm (0.000004 inch). This very small size is a result of the process used to form the particles and is not particularly desirable, as the particles are almost too fine to settle out of suspension.

6. **Magnetic Particle inspection cannot be used to detect internal defects. Why? [AM2017]**

It may not be suitable for inspecting components with complex geometries or hard-to-reach areas. Material Limitations: This method is limited to ferromagnetic materials only. Non-ferromagnetic materials like aluminum or copper cannot be inspected using this type of testing.

7. **Mention any two materials that can be used as developers in LPT? [ND2018]**
   - Dry powder (fine powder form)
   - water soluble (used for liquid dip tanks application)
   - water suspensible (used for liquid dip tanks application)
   - nonaqueous - for fluorescent (aerosol spray can)
   - nonaqueous - for Visible (aerosol spray can)

8. **What is the effect of shape and size of magnetic particles on the Inspection process? [ND2018]**

With decreasing particle sizes, the magnetization decreases while the coercivity increases, which is attributed to the magnetically disordered surface layer.

9. **State the desirable characteristics of a good developer [ND2021]**

   - The material must be absorptive, to perform blotting action.
   - It must have a fine texture but not be too fine, as this may block imperfections.
   - For colour contrast penetrants it must mask out background contours and colours.
   - It must be easily and evenly applicable.

10. **What types of defects can be detected in a liquid penetrant test?[ND2021]**

Liquid penetrant testing (PT) is a one of non-destructive test, which can detect surface-breaking defects-such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks.

11. **Components teste by magnetic particle testing has to be demagnetized. Why? [ND2017]**
Workpieces made of magnetic materials are prone to becoming magnetized during machining, drilling, lasering, or other manipulation. That may cause difficulties when doing subsequent work with magnetized workpieces—they attract dirt and may generally become more difficult to machine.

12. **Liquid penetrant testing is not applicable for porous material- give reasons. [ND2017]**
Penetrant inspection will find discontinuities open to the surface on ferrous and nonferrous metals. Penetrant testing should not be done on porous surfaces, as the pores will act as discontinuities to trap penetrant and prevent accurate inspection.

PART - B & C (13MARKS)

1. **Explain how the liquid penetrant test be used to detect surface discontinuities? Explain the various stages of liquid penetrant testing procedure.**

Liquid Penetrant Testing (LPT): Overview

Liquid Penetrant Testing (LPT) is a **non-destructive testing (NDT)** method used to detect **surface discontinuities** such as cracks, porosity, seams, laps, and other surface-breaking defects in non-porous materials. The process involves applying a liquid dye (penetrant) to the surface of a material, which seeps into surface-breaking defects by capillary action. After removing the excess penetrant, a developer is applied, making the penetrant in the defects visible, either under visible light or ultraviolet light.

This method is widely used in industries like aerospace, automotive, and manufacturing because it is simple, cost-effective, and versatile.

Detection of Surface Discontinuities Using LPT

1. **Capillary Action**: When a liquid penetrant is applied to the material's surface, it seeps into surface cracks or other discontinuities through capillary action. This action allows the penetrant to fill small defects that may not be visible to the naked eye.
2. **Visual Indication**: After the penetrant is allowed to dwell for some time, excess liquid is removed, and a developer is applied. The developer draws out the penetrant trapped in defects, creating a visual indication (usually a colored or fluorescent mark) that helps inspectors identify surface defects.

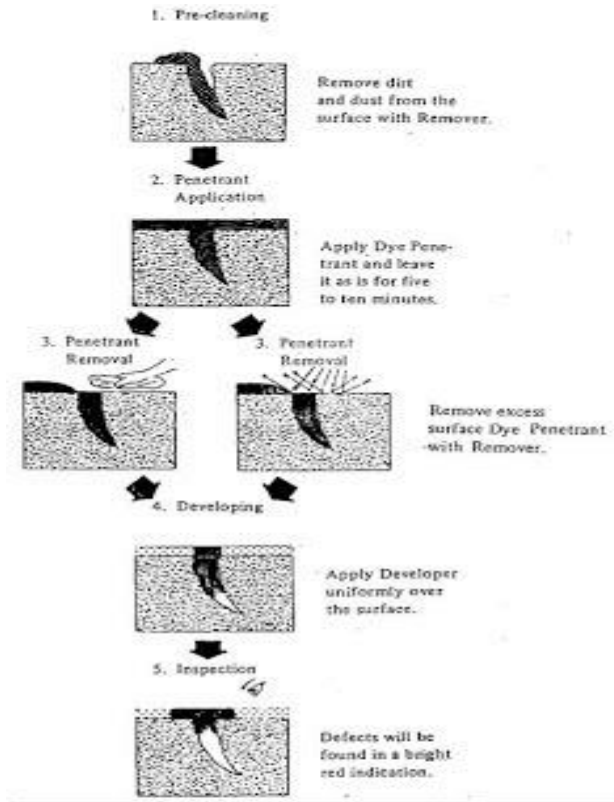
LPT is particularly useful for detecting:

- **Hairline cracks** caused by fatigue, quenching, or grinding.
- **Porosity** in welds, castings, or machined components.

- **Seams** and **laps** in forged or rolled products.

Stages of Liquid Penetrant Testing Procedure

The liquid penetrant test follows a systematic sequence of steps to ensure accurate detection of surface discontinuities. The following are the various stages involved:



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1. Surface Cleaning (Pre-Cleaning)

- **Objective**: Remove any contaminants such as oil, grease, dirt, paint, or other surface coatings that might interfere with the penetrant's ability to enter surface defects.
- **Method**: The surface is cleaned using solvents, detergents, or mechanical cleaning methods (e.g., sandblasting).
- **Importance**: Proper cleaning is crucial, as contaminants can block the penetrant from entering defects, leading to false negatives.

---

2. Application of Penetrant

- **Objective**: Apply the liquid penetrant to the surface of the material to allow it to seep into any surface discontinuities.
- **Types of Penetrants**:
  - **Visible Penetrants**: These are colored (usually red) and can be seen under normal light.
  - **Fluorescent Penetrants**: These glow under ultraviolet (UV) light, offering higher sensitivity for detecting fine cracks.
- **Method**: The penetrant is applied by spraying, brushing, or dipping, ensuring the entire surface is covered.

3. Penetrant Dwell Time

- **Objective**: Allow sufficient time for the penetrant to seep into any surface defects.
- **Duration**: The dwell time depends on the material, the size of the defects, and the type of penetrant used. It typically ranges from **5 to 30 minutes**.
- **Importance**: The penetrant must have enough time to enter even very fine cracks. Too short a dwell time may result in incomplete penetration, while too long can lead to over-penetration or drying.

---

4. Excess Penetrant Removal

- **Objective**: Remove the excess penetrant from the surface without removing the penetrant trapped in defects.
- **Method**:
  - **Water-Washable Penetrants**: These are removed by rinsing with water.
  - **Solvent-Removable Penetrants**: A lint-free cloth dampened with solvent is used to gently wipe the surface.
  - **Post-Emulsifiable Penetrants**: An emulsifier is applied to make the excess penetrant water-soluble before rinsing.
- **Importance**: This step must be done carefully to avoid removing the penetrant from the defects.

---

5. Application of Developer

- **Objective**: Draw out the penetrant from defects to form visible indications on the surface.
- **Types of Developers**:
  - **Dry Powder**: Applied as a fine powder, which absorbs the penetrant from the defects.
  - **Wet Developer (Solvent-based or Water-based)**: Sprayed onto the surface as a liquid, leaving a thin white film that absorbs and contrasts with the penetrant.
- **Method**: The developer is either sprayed, brushed, or dipped onto the surface. It acts as a blotter, drawing out the penetrant from the defects to enhance visibility.
- **Dwell Time**: After applying the developer, a short development time (usually around 10 minutes) allows the penetrant to emerge from the defect and create a clear, visible indication.

---

6. Inspection

- **Objective**: Examine the surface for visible indications of discontinuities.
- **Method**:
  - **Visible Penetrant**: Inspected under normal lighting conditions.
  - **Fluorescent Penetrant**: Inspected under ultraviolet (UV) light in a darkened room.
- **Indications**: The penetrant trapped in defects will show up as visible marks (colored or fluorescent), highlighting the location and size of surface discontinuities such as cracks, seams, or porosity.
- **Recording Results**: The inspector documents the size, shape, and location of the defects, often photographing them for records.

---

7. Post-Cleaning

- **Objective**: Remove any remaining penetrant and developer from the material's surface after inspection.
- **Method**: The surface is cleaned using appropriate solvents or water to restore the material to its original state.

- **Importance**: Proper cleaning is essential, especially if the part is to be used in service after testing, to prevent any contamination.

Diagram of Liquid Penetrant Testing Procedure:

1. **Surface Cleaning** → 2. **Penetrant Application** → 3. **Dwell Time** → 4. **Excess Penetrant Removal** → 5. **Developer Application** → 6. **Inspection** → 7. **Post-Cleaning**

Advantages of Liquid Penetrant Testing

- **Simple and cost-effective**.
- Can detect **very fine surface defects**.
- **Applicable to a wide range of materials**, including metals, ceramics, and plastics (non-porous surfaces).
- **Portable** and can be used on-site or in the lab.
- Can be used on **complex shapes and large areas**.

Limitations of Liquid Penetrant Testing

- Only detects **surface-breaking defects**. Subsurface defects cannot be identified.
- Cannot be used on **porous materials**, as the penetrant may seep into the material, leading to false indications.
- Requires **proper surface preparation** and cleaning, as contaminants can obstruct defect detection.
- **Penetrant removal** can be challenging if it has seeped deeply into rough surfaces.

2. **Discuss about longitudinal magnetization and circumferential magnetization in magnetic particle testing with neat sketch.**

Magnetic Particle Testing (MPT)

Magnetic Particle Testing (MPT) is a **non-destructive testing (NDT)** method used to detect surface and near-surface discontinuities in ferromagnetic materials. The process involves magnetizing the material and applying fine magnetic particles, which gather at regions where magnetic field leakage occurs, indicating the presence of defects like cracks or discontinuities.

MPT relies on the direction of the magnetic field with respect to the defect. To detect flaws effectively, the magnetic field must be perpendicular to the defect. There are two primary methods of magnetization in MPT:

1. **Longitudinal Magnetization**
2. **Circumferential Magnetization**

Both techniques create distinct magnetic fields within the material, allowing for the detection of different types of defects.

---

1. Longitudinal Magnetization

Longitudinal magnetization is the process of inducing a magnetic field that runs parallel to the length of the component. It is typically used for detecting defects that are **perpendicular** to the direction of the magnetic field (i.e., **circumferential cracks** around the component).

- **Method**: A longitudinal magnetic field is generated by passing an electric current through a solenoid coil surrounding the component. The magnetic field lines run parallel to the long axis of the part.
- **Application**:
  - Best suited for detecting **circumferential cracks**, seams, or laps on shafts, rods, tubes, or other elongated parts.
  - Effective for finding defects on the outer surface and shallow subsurface defects.

How It Works:

- When a part is magnetized longitudinally, magnetic field lines run parallel to the length of the component.
- If a **defect** like a circumferential crack is present, the magnetic field is disturbed, creating a **magnetic flux leakage** at the location of the crack. This leakage attracts magnetic particles, indicating the location of the defect.

```
+-----------------------------+
|                             |
| Longitudinal Magnetic Field |
|(Along the length of the part)
|                             |
+-----------------------------+

                 |
 Circumferential Defect (e.g., crack)
                 |
   Magnetic Particles Accumulation
```

---

2. Circumferential Magnetization

Circumferential magnetization generates a magnetic field that circles around the circumference of the component. This method is ideal for detecting **longitudinal defects**, such as cracks that run along the length of the part.

- **Method**: Circumferential magnetization is created by passing a current directly through the component itself (direct magnetization), or by using external contacts or clamps. This sets up a magnetic field that flows around the circumference of the part.
- **Application**:
  - Best for detecting **longitudinal cracks** or defects that run along the length of pipes, tubes, rods, or shafts.
  - Useful for finding both surface and shallow subsurface defects in cylindrical parts.

How It Works:

- In circumferential magnetization, magnetic lines of force wrap around the circumference of the part.
- If a **longitudinal defect** (parallel to the axis) exists, it disturbs the magnetic field, causing **flux leakage**. This attracts magnetic particles to the defect site, revealing its location.

```
|   Circumferential Magnetic Field     |
| (Around the part’s circumference)    |


                    |
  Longitudinal Defect (e.g., crack)
                    |
   Magnetic Particles Accumulation
```

Key Differences

Feature	Longitudinal Magnetization	Circumferential Magnetization
Magnetic Field Direction	Parallel to the length of the component (along the longitudinal axis).	Around the circumference of the component (circular around the surface).
Detects Defects	Best for detecting circumferential defects (cracks perpendicular to the length).	Best for detecting longitudinal defects (cracks running along the length).
Magnetization Method	Achieved using a solenoid or yoke.	Achieved by passing current through the component or using clamps/contacts.
Typical Components Tested	Shafts, rods, bars, pipes, elongated parts.	Cylindrical components like rods, pipes, and rings.
Common Application	Inspects for circumferential cracks, seams, and laps.	Inspects for longitudinal cracks and defects along the part's axis.

Combination of Both Methods

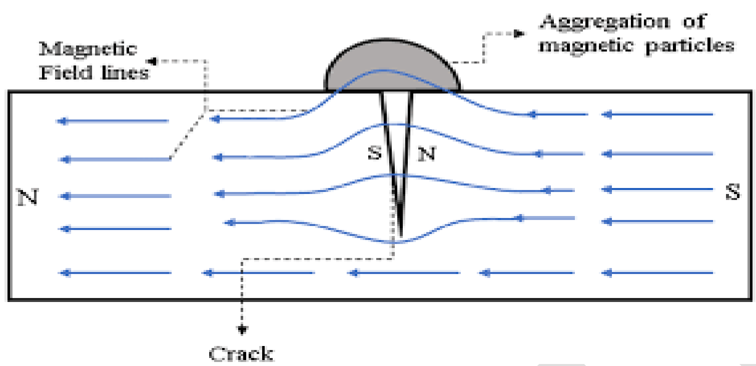
In some cases, both longitudinal and circumferential magnetization may be used together to detect defects in different orientations. This ensures thorough inspection and detection of defects that could be missed if only one method is used.

3. **With neat sketch explain magnetic particle Inspection method and its merits, demerits and application.**

Magnetic Particle Inspection (MPI):

Magnetic Particle Inspection (MPI) is a **non-destructive testing (NDT)** method used to detect surface and slightly subsurface discontinuities in ferromagnetic materials. It works by inducing a magnetic field in the component and then applying fine magnetic particles (either dry or suspended in a liquid) to the surface. Discontinuities in the material disturb the magnetic field, causing a **magnetic flux leakage**, which attracts the magnetic particles to form visible indications of the defect.

MPI is commonly used in industries such as aerospace, automotive, and manufacturing to inspect components like castings, forgings, and welds.



Magnetic Particle Inspection Process (with Sketch)

The MPI process can be broken down into several key steps:

1. Surface Preparation

- The surface must be **clean and free of contaminants** (oil, grease, dirt, etc.) that could prevent the magnetic particles from indicating defects. Surface cleaning can be done using solvents or mechanical methods.

2. Magnetization

- The component is **magnetized** using one of two methods: longitudinal or circular magnetization. The magnetic field is either induced by passing current through the component (direct magnetization) or by applying an external magnetic field (indirect magnetization using a coil or yoke).
  - **Direct Magnetization**: A current is passed directly through the component, creating a magnetic field.
  - **Indirect Magnetization**: A current is passed through a coil or yoke, creating a magnetic field in the component.

  Magnetic Flux lines form in the material, flowing through it. If a surface or subsurface defect is present, it will disturb the magnetic field, causing a flux leakage.

3. Application of Magnetic Particles

- Once the component is magnetized, **magnetic particles** (either in dry powder form or suspended in a liquid) are applied to the surface.
  - These particles are attracted to areas of **magnetic flux leakage**, such as cracks or defects, and will cluster around the discontinuity, forming visible indications of the defect.

4. Inspection

- The surface is then visually inspected under suitable lighting:

- **Visible Magnetic Particles**: Inspected under white light.
- **Fluorescent Magnetic Particles**: Inspected under ultraviolet (UV) light.

The magnetic particles will **accumulate at the defect** locations, forming visible indications of the size, shape, and position of discontinuities.

5. Demagnetization and Post-Cleaning

- After the inspection, the component is **demagnetized** to remove any residual magnetism. Any remaining magnetic particles are cleaned off the surface, returning the component to its original state.

Neat Sketch of MPI Process

The following steps can be illustrated in a diagram:

1. **Surface Preparation**
2. **Magnetization**
3. **Application of Magnetic Particles**
4. **Magnetic Flux Leakage and Particle Accumulation at Defects**

4. **Discuss about the various ways of magnetizing the component in NDT.**

In **Magnetic Particle Testing (MPT)**, one of the most critical steps is to magnetize the component being inspected. The magnetization process creates a magnetic field in the material, and if any discontinuities like cracks, voids, or inclusions are present, they will disturb the magnetic field, causing **magnetic flux leakage**. This leakage attracts magnetic particles, highlighting the defect.

The effectiveness of Magnetic Particle Testing depends largely on the magnetization technique used, as the magnetic field must be oriented perpendicular to the defect to produce flux leakage. Several methods can be used to magnetize the component, each suited to different shapes and types of materials.

Here are the **various ways of magnetizing the component in NDT**:

---

1. Longitudinal Magnetization

- **Method**: Longitudinal magnetization creates a magnetic field that runs parallel to the long axis of the component.
- **Technique**: This can be achieved using a **solenoid** or **coil** that surrounds the component, which creates a longitudinal magnetic field when an electric current flows through the coil.
  - **Application**: Best suited for detecting **circumferential defects** such as cracks that run around the outer surface of cylindrical objects like pipes, rods, or shafts.
- **Magnetic Field Orientation**: The magnetic field lines are parallel to the length of the component, and flux leakage occurs at defects that are perpendicular to the field (e.g., circumferential cracks).

---

2. Circular Magnetization (Direct Magnetization)

- **Method**: In circular magnetization, the magnetic field is generated around the circumference of the component. This can be achieved by passing an electric current directly through the part.
- **Technique**: The part itself becomes a **conductor** for the current, and this induces a **circular magnetic field** around the part's surface.
  - **Application**: Ideal for detecting **longitudinal defects** (e.g., cracks that run along the length of pipes, rods, or shafts).
- **Magnetic Field Orientation**: The magnetic field runs around the circumference of the component, and flux leakage occurs at defects that are parallel to the length of the component (e.g., longitudinal cracks).

---

3. Yoke Magnetization

- **Method**: A **yoke** is a horseshoe-shaped electromagnet or permanent magnet that applies a magnetic field locally to the area being inspected.
- **Technique**: A magnetic yoke is placed on the surface of the material, and a magnetic field is induced between the poles of the yoke. The current runs through the yoke, and the magnetic field passes through the material between the poles.
  - **Application**: Best suited for **localized inspections** of large parts or for parts with complex shapes where using coils or direct current is not practical. It is often used for **field inspections**.
- **Magnetic Field Orientation**: The field is created between the poles of the yoke, and flux leakage occurs at defects that are perpendicular to the magnetic field.

---

4. Prods Magnetization (Direct Contact Magnetization)

- **Method**: In **prods magnetization**, two electrically charged probes (prods) are placed in contact with the surface of the material, and a direct current is passed between them.
- **Technique**: The current passing through the material between the prods creates a magnetic field around the area. Magnetic particles are applied to the area where the current flows.
  - **Application**: Used for inspecting **welds**, large castings, or irregularly shaped components. This method can be used in situations where it is difficult to apply coils or yokes.
- **Magnetic Field Orientation**: The magnetic field flows in circular paths around the current path between the prods, making it ideal for detecting surface defects.

---

5. Coil Magnetization

- **Method**: The component is placed inside or near a **coil** of wire carrying an electric current. This generates a magnetic field that runs through the component.
- **Technique**: When a current flows through the coil, it generates a longitudinal magnetic field inside and around the component.
  - **Application**: Ideal for inspecting **bars, rods, and other elongated parts**. This method is used for **longitudinal magnetization** and detects circumferential defects.
- **Magnetic Field Orientation**: The field is parallel to the axis of the component, and flux leakage occurs at defects that are perpendicular to the field (e.g., circumferential cracks).

6. Central Conductor Magnetization

- **Method**: A **central conductor** (a bar or wire) is passed through the hollow center of a part, such as a ring or tube, and current is applied through the conductor.
- **Technique**: The current creates a circular magnetic field in the component, which is strongest at the inner surface of the hollow part.
  - **Application**: Best for detecting **longitudinal defects** in hollow or cylindrical components like rings, tubes, and pipes.
- **Magnetic Field Orientation**: The magnetic field forms circular loops around the conductor, and flux leakage occurs at defects parallel to the length of the part (e.g., longitudinal cracks).

---

7. Induced Current Magnetization

- **Method**: In **induced current magnetization**, a high-frequency alternating current (AC) is passed through a component, inducing eddy currents that create a magnetic field around the part.
- **Technique**: The component is placed in a coil carrying alternating current, and eddy currents are induced in the component, generating a magnetic field.
  - **Application**: Effective for detecting **surface cracks** in **thin or small components**. Often used for **non-contact magnetization**.
- **Magnetic Field Orientation**: Eddy currents create a magnetic field, and flux leakage occurs at surface discontinuities.

Magnetization Methods and Defect Detection

Each of these methods creates different magnetic field orientations, which makes them effective for detecting defects in specific orientations:

- **Longitudinal Magnetization**: Detects circumferential defects.
- **Circular Magnetization**: Detects longitudinal defects.
- **Yoke and Prod Methods**: Provide flexibility for local or spot inspections.
- **Coil and Central Conductor**: Good for cylindrical components.

Summary

Method	Magnetic Field Orientation	Best For Detecting	Application
Longitudinal Magnetization	Parallel to the component's length	Circumferential defects	Shafts, rods, pipes
Circular Magnetization	Around the circumference of the component	Longitudinal defects	Cylindrical parts, welds
Yoke Magnetization	Local magnetic field between yoke poles	Surface and shallow subsurface defects	Field inspections, complex shapes
Prods Magnetization	Circular magnetic field between two contact points	Surface defects near the contact points	Welds, large castings

Method	Magnetic Field Orientation	Best For Detecting	Application
Coil Magnetization	Parallel to the axis of the component	Circumferential defects	Bars, rods, and elongated parts
Central Conductor	Circular magnetic field around the central conductor	Longitudinal defects in hollow parts	Rings, tubes, and hollow cylindrical components
Induced Current Magnetization	Surface magnetic field generated by eddy currents	Surface cracks	Thin and small components, non-contact magnetization

Each method has specific advantages and is chosen based on the material's shape, size, and defect orientation that needs to be detected. These magnetization techniques make MPI versatile for inspecting a wide range of components in various industries.

5. **Explain the post emulsifying lipophilic and solvent removable methods in Liquid penetrant Testing using the Process flow diagram.**

Liquid Penetrant Testing (LPT) Overview

Liquid Penetrant Testing (LPT) is a **non-destructive testing (NDT)** method used to detect surface-breaking defects in non-porous materials like metals, ceramics, and plastics. It involves applying a penetrant liquid to the surface of a component, allowing it to seep into any defects, and then using a developer to draw the penetrant back to the surface to reveal the defect.

LPT can be carried out using several methods for removing the penetrant after it has been applied. Two common methods are:

1. **Post-Emulsifying (Lipophilic) Method**
2. **Solvent-Removable Method**

Both methods differ in the way the excess penetrant is removed after the dwell time, as well as the types of penetrants and emulsifiers used.

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1. Post-Emulsifying Lipophilic Method

Post-emulsifying refers to the process in which the penetrant does not emulsify (i.e., mix with water) until an emulsifier is applied. This method is used when a penetrant is oil-based (lipophilic) and cannot be easily washed off with water without the addition of an emulsifier.

Process Flow Diagram for Post-Emulsifying Lipophilic Method:

1. **Surface Preparation**:
   - Clean the part to remove dirt, oil, and other contaminants.
2. **Penetrant Application**:
   - Apply the **lipophilic penetrant** (oil-based).
   - Allow it to dwell for the appropriate time to penetrate surface flaws.
3. **Emulsifier Application**:
   - Apply the **lipophilic emulsifier** (oil-based) to the penetrant-covered surface.
   - The emulsifier turns the penetrant into a water-washable form.
4. **Excess Penetrant Removal**:

   - Wash the part with water to remove the emulsified penetrant.
5. **Drying**:
   - Dry the part using warm air or other drying techniques.
6. **Developer Application**:
   - Apply a **developer** (powder or liquid) to draw the penetrant from the defects.
7. **Inspection**:
   - Inspect the part under visible light or UV light for fluorescent penetrants.
   - The penetrant drawn out by the developer will highlight defects.
8. **Post-Cleaning**:
   - Clean the part to remove any remaining developer and penetrant.

Process Flow Diagram (Simplified)

```
+---------------------+       +--------------------+     +---------------------+
| Surface Cleaning    |   -->  | Penetrant Application |   -->   | Emulsifier
Application |
+---------------------+       +--------------------+     +---------------------+
        ↓                       ↓                         ↓
+---------------------+       +--------------------+     +---------------------+
| Excess Penetrant    |   -->  | Drying              |   -->   | Developer
  Application |
| Removal (Water Wash)|       +--------------------+     +---------------------+
+---------------------+                                             ↓
                        +---------------------+      +---------------------+
                        | Inspection          |  -->   | Post-Cleaning       |
                        +---------------------+      +---------------------+
```

Advantages of the Post-Emulsifying Lipophilic Method:

- **Control over emulsification**: The emulsifier is applied separately, giving better control over the emulsification process.
- **Better for complex geometries**: Provides better control for parts with complex shapes or deep cracks.
- **High sensitivity**: This method is capable of detecting very small defects.

Disadvantages:

- **More process steps**: It requires an additional step of applying the emulsifier.
- **Longer time**: The process is more time-consuming due to the need to apply and remove the emulsifier.

---

2. Solvent-Removable Method

The **solvent-removable** method uses a solvent-based penetrant and removes the excess penetrant using a cleaning solvent. This method is commonly used when water or emulsifiers are not suitable for the application or material.

Process Flow Diagram for Solvent-Removable Method:

1. **Surface Preparation**:
   - Clean the part to remove dirt, oil, and other contaminants.
2. **Penetrant Application**:
   - Apply the **solvent-based penetrant**.
3. **Dwell Time**:
   - Allow the penetrant to dwell, giving it time to enter any surface-breaking defects.
4. **Excess Penetrant Removal**:

    - Use a **solvent** (such as a penetrant remover) to wipe off the excess penetrant with clean, lint-free cloths or wipes.
5. **Drying**:
    - Air-dry the component after excess penetrant removal.
6. **Developer Application**:
    - Apply a **developer** to draw the penetrant out of the defects.
7. **Inspection**:
    - Inspect the component under white light or UV light, depending on the type of penetrant used.
8. **Post-Cleaning**:
    - Clean the part to remove any remaining developer and penetrant.

Process Flow Diagram (Simplified)

```
+---------------------+          +--------------------+     +-----------------
| Surface Cleaning    |   -->    | Penetrant Application |    -->   | Solvent Removal
of Penetrant |
+---------------------+          +--------------------+     +---------------------+
        ↓                                                  ↓
+---------------------+          +--------------------+     +---------------------+
| Drying              |   -->    | Developer Application |   -->   | Inspection
|
+---------------------+          +--------------------+     +---------------------+
                                                         ↓
                                      +---------------------+
                                      | Post-Cleaning        |
                                      +---------------------+
```

Advantages of the Solvent-Removable Method:

- **Simplicity**: Fewer steps than the post-emulsifying method.
- **Quick removal**: Solvents can quickly remove the excess penetrant without the need for emulsifiers or water.
- **Suitable for sensitive materials**: Ideal for materials that cannot tolerate water or emulsifiers.

Disadvantages:

- **Lower sensitivity**: May not be as sensitive as other methods for detecting very fine cracks.
- **Solvent use**: The use of solvents may be hazardous and require proper ventilation and safety measures.

Comparison of Post-Emulsifying and Solvent-Removable Methods

Feature	Post-Emulsifying (Lipophilic)	Solvent-Removable
Excess Penetrant Removal	Requires emulsifier before water wash	Solvent wipes off penetrant directly
Penetrant Type	Lipophilic (oil-based)	Solvent-based
Sensitivity	High	Moderate
Complexity	More complex due to additional emulsifier step	Simpler and faster
Application	Best for complex geometries and critical inspections	Best for smaller, simpler parts
Environment	Requires water and emulsifiers	Solvents, requiring ventilation

UNIT III EDDY CURRENT TESTING & THERMOGRAPHY

Eddy Current Testing: Generation of eddy currents– properties– eddy current sensing elements, probes, Instrumentation, Types of arrangement, applications, advantages, limitations – Factors affecting sensing elements and coil impedance, calibration, Interpretation/Evaluation Thermography- Principle, Contact & Non-Contact inspection methods, Active & Passive methods, Liquid Crystal – Concept, example, advantages & limitations. Electromagnetic spectrum, infrared thermography- approaches, IR detectors, Instrumentation and methods, applications.

PART - A (2 MARKS)

1. **Define Thermography. [AM2018]**

   Thermography is a generic term that refers to an imaging method based on temperature readings. The idea behind thermography is that heat energy given off by components can provide information about their operating conditions. It works by detecting the levels of IR emitted by an observed body.

2. **Write the Principle of Eddy Current Testing [AM2018]**
Eddy currents are produced on the surface of any electrical conducting material where an alternating magnetic field is generated by AC coil. In case that there is a crack on the surface of the material, circulation of the eddy currents is disturbed by the crack.

3. **How eddy current is generated? [AM2019]**
Eddy currents are produced due to changes in the magnetic field. They are created when a conductor moves through a magnetic field or when the magnetic field around a stationary conductor varies.

4. **What is the prominent mechanism of Plastic deformation in Metals and define it? [AM2019]**
The prominent mechanism of plastic deformation in metals is called "slip," which involves the sliding of crystal blocks over one another along specific crystallographic planes, known as slip planes, when a shear stress exceeding a critical value is applied; essentially, it's like a deck of cards sliding past each other when pushed from one end

5. **What is radio frequency mode in Ultrasonic Testing? [AM20217]**
Radio frequency (RF) signals are used in ultrasonic testing (UT) to generate ultrasonic waves that can be used in non-destructive testing to detect discontinuities in materials

6. **How does the depth of penetration of Eddy current is affected by the Frequency of the Current? [AM20217]**
The depth of penetration of eddy currents decreases as the frequency of the current increases; meaning, higher frequencies result in eddy currents that are more concentrated near the surface of a material, while lower frequencies penetrate deeper into the material - this phenomenon is known as the "skin effect.

7. **Differentiate between Active and Passive Thermography? [ND2018]**
Passive thermography does not require any active illumination (such as lights) or specialized equipment, making it extremely useful for inspections in dark or enclosed spaces. Active thermography is the use of emitters to illuminate objects with infrared light and then take images using an infrared camera.

8. **What are the characteristics of Eddy Current? [ND2018]**
Properties of the Eddy currents in conductors of non-zero resistivity generate heat as well as electromagnetic forces. The heat can be used for induction heating. The electromagnetic forces can be used for levitation, creating movement, or to give a strong braking effect.

9. **State at least two properties of eddy current. [ND2021]**
Eddy currents in conductors of non-zero resistivity generate heat as well as electromagnetic forces.

10. **Enumerate the instruments used for infrared detection. [ND2021]**
Infrared detectors are used to measure the intensity of infrared radiation, and can be categorized as either thermal or photon detectors

11. **What is the principle behind eddy current testing? [ND2017]**
The principle behind ECT is that when a changing magnetic field is brought close to a conductive material, it induces small circulating currents called eddy currents in the material.

12. **What are the uses of penetrameter? [ND2017]**
A penetrometer is a device that measures how much a substance resists penetration, and it has many uses across a number of industries

PART - B & C (13MARKS)

1. **Explain the eddy current and ultrasonic based NDT methods to analyze the flaws in pipe fittings.**

Non-destructive testing (NDT) methods, like **eddy current** and **ultrasonic testing**, are widely used to detect flaws in pipe fittings. They offer the advantage of identifying defects without damaging the material. Here's how each method works for analyzing flaws in pipe fittings:

---

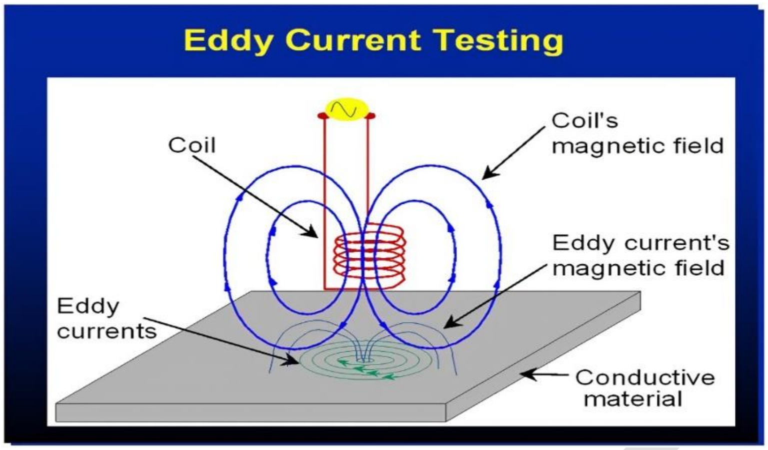
1. Eddy Current Testing (ECT)

Principle:

Eddy current testing is based on the principle of electromagnetic induction. When an alternating current flows through a coil, it generates a magnetic field. This magnetic field induces circulating currents, known as eddy currents, in the conductive material (like metal pipes). Flaws in the material, such as cracks, corrosion, or voids, disrupt these currents, causing measurable changes in the electromagnetic response.

How it Works for Pipe Fittings:

- A probe with a coil is placed on the surface of the pipe fitting.
- The coil generates an alternating magnetic field that induces eddy currents in the metal.
- Variations in the eddy currents (caused by defects) alter the impedance of the probe, which is recorded and analyzed.
- The probe can scan over the surface of the pipe to detect flaws such as surface cracks, corrosion, and wall thinning.



Advantages:

- Suitable for detecting surface or near-surface flaws.
- Fast, with real-time results.
- No need for direct contact with the pipe surface (can even work through coatings).

Limitations:

- Limited to conductive materials (mostly metals).
- Primarily detects surface and shallow defects; less effective for deep internal flaws.

Common Defects Detected:

- Surface cracks
- Corrosion spots
- Weld defects in pipe fittings

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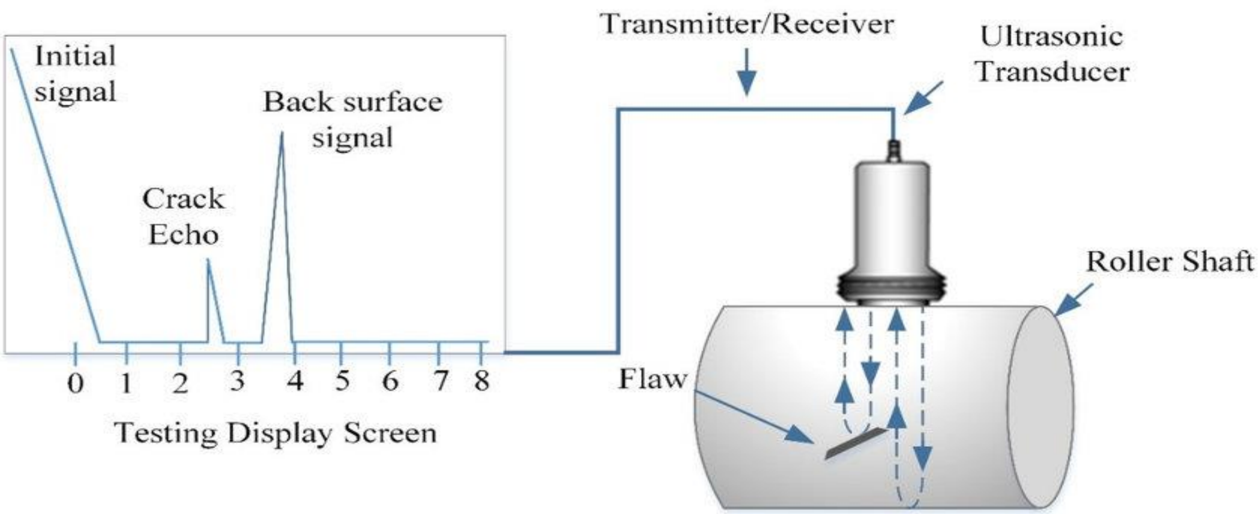
2. Ultrasonic Testing (UT)

Principle:

Ultrasonic testing uses high-frequency sound waves to detect internal flaws in materials. A transducer generates ultrasonic waves that travel through the material. When these waves encounter a discontinuity, such as a crack or void, part of the sound is reflected back to the transducer. The time it takes for the echo to return is used to determine the location and size of the flaw.



How it Works for Pipe Fittings:

- A transducer (probe) sends ultrasonic pulses into the pipe material.
- These sound waves propagate through the material until they encounter a boundary (flaw or change in material properties), at which point they reflect back to the transducer.
- The reflected signals are analyzed to identify the depth and size of the flaws inside the pipe.
- By scanning along the surface of the pipe fitting, a detailed image of internal flaws can be obtained.

Advantages:

- Capable of detecting deep internal flaws.
- Provides detailed information about flaw size, location, and depth.
- Can be used on various materials, including metals, plastics, and ceramics.

Limitations:

- Requires a coupling medium (like gel or water) between the transducer and pipe.
- Surface preparation is necessary for good contact.
- More complex and time-consuming compared to eddy current testing.

Common Defects Detected:

- Internal cracks
- Inclusions or voids
- Corrosion and wall thinning
- Defects in welds or joints

Comparison:

Method	Eddy Current Testing (ECT)	Ultrasonic Testing (UT)
Best For	Surface and near-surface defects	Deep internal defects
Material	Conductive materials (e.g., metals)	Most materials (metals, plastics, etc.)
Penetration Depth	Limited to surface or shallow depth	Deep penetration, suitable for thick materials
Speed	Fast, real-time	Slower, requires more scanning
Resolution	High for surface defects	High for internal defects
Surface Preparation	Minimal	Requires coupling agent and clean surface

2. **Explain the instrumentation and various methods of thermography inspection.**

Thermography Inspection: Instrumentation and Methods

Thermography, or infrared (IR) thermography, is a non-destructive testing (NDT) method that detects thermal patterns and temperature variations on the surface of objects. These thermal patterns can be used to identify underlying defects in materials, such as cracks, delaminations, or voids. It is widely used in industries like aerospace, energy, and construction for monitoring the integrity of components and structures.

1. Instrumentation for Thermography Inspection

Thermography systems typically consist of several key components:

a. Infrared Camera:

- The core component of a thermographic inspection is the infrared (IR) camera. This camera detects infrared radiation emitted by the surface of an object and converts it into a visible heat map (thermogram).
- **Key Features:**
  - **Spectral Range:** Typically 3–14 micrometers (µm), depending on the camera type (short-wave, medium-wave, or long-wave IR cameras).
  - **Detector Type:** Focal Plane Array (FPA) detectors are commonly used, with materials like InSb (Indium Antimonide) or HgCdTe (Mercury Cadmium Telluride).
  - **Temperature Sensitivity:** Cameras can detect temperature variations as small as 0.01°C.
  - **Resolution:** A high-resolution camera provides a more detailed thermogram, typically in megapixels.

b. Data Acquisition System:

- The camera is connected to a data acquisition system, typically a computer with specialized software, that captures, stores, and processes the thermal images. The software analyzes the temperature variations and generates reports.

c. Calibration Source (Blackbody Source):

- For accurate temperature measurements, thermography systems are often calibrated using a **blackbody source**, which is an ideal emitter of thermal radiation at a known temperature.

d. Heating Sources (for Active Thermography):

- In active thermography, external heat sources like halogen lamps, lasers, or ultrasonic transducers may be used to heat the object, enhancing defect visibility.

---

2. Methods of Thermography Inspection

There are two primary categories of thermography inspection methods:

A. Passive Thermography:

- **Principle:** In passive thermography, the object naturally emits heat due to its operational conditions, and the IR camera simply captures the natural temperature variations across the surface.
- **Application:**
    - Ideal for applications where the object is naturally at an elevated temperature, such as electrical systems, boilers, or running machinery.
    - Used for detecting **hot spots** in electrical circuits, **heat losses** in insulation, or **overheating components** in mechanical systems.

Advantages:

- Simple setup with no need for external heat sources.
- Non-invasive and ideal for real-time monitoring of equipment during operation.

Limitations:

- Not ideal for detecting shallow or subtle defects.
- The object must be operating or naturally emit heat differences for detection.

B. Active Thermography:

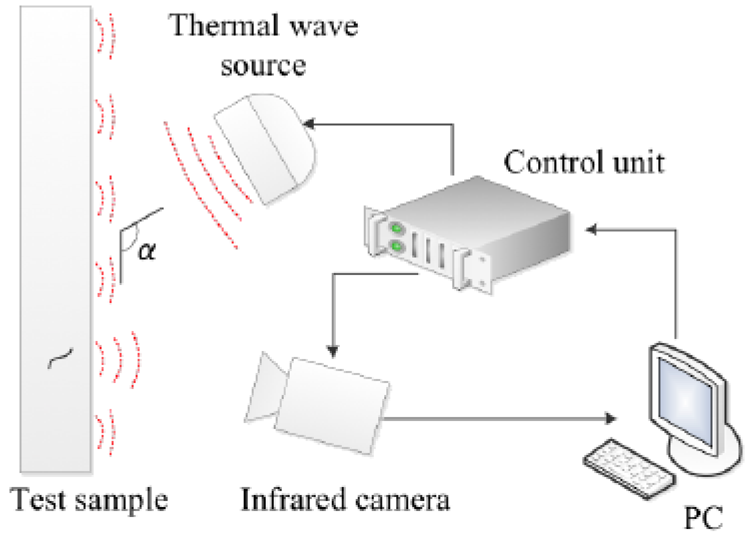
- **Principle:** Active thermography involves applying an external heat source to the object to induce thermal contrast between normal and defective areas. Defects such as cracks, voids, or delaminations cause differences in thermal conductivity, making them visible on the thermogram.
- **Application:**
    - Commonly used in materials inspection, composite testing, and weld inspections.
    - Ideal for detecting **subsurface defects** that do not generate enough natural thermal contrast on their own.

There are several methods within active thermography, based on how heat is applied and analyzed:

---

i. Pulse Thermography:

- **Process:** A short, intense pulse of energy (typically from a flash lamp or laser) is applied to the surface of the material. The surface heats up rapidly, and the IR camera records how the heat dissipates over time.
- **Defect Detection:** Subsurface defects disrupt the heat flow, causing temperature variations visible in the cooling process.



Advantages:

- Fast and efficient for detecting shallow subsurface defects.
- Can inspect large areas quickly.

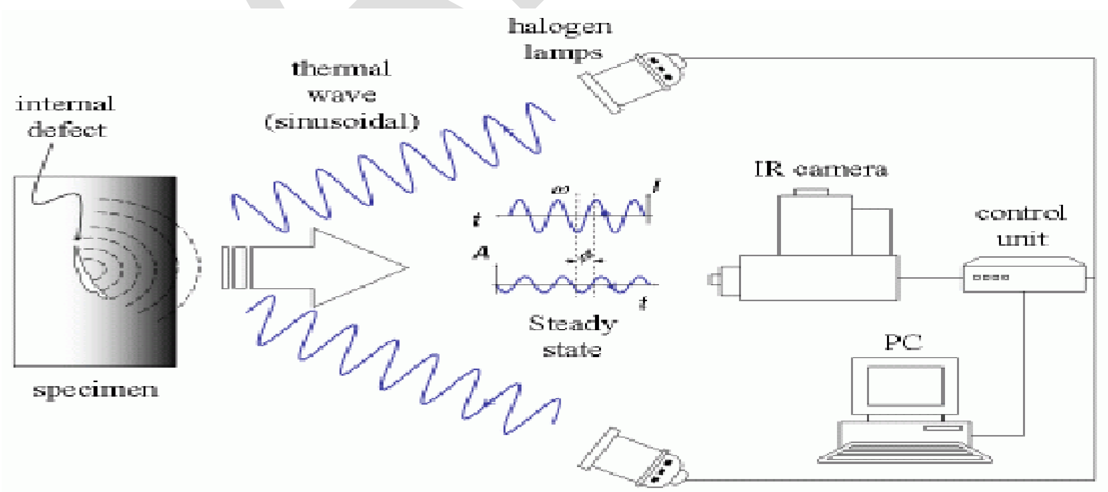
Limitations:

- Limited penetration depth, typically up to a few millimeters.
- Requires specialized equipment like flash lamps.

---

ii. Lock-in Thermography:

- **Process:** A periodic (sinusoidal) heat source is applied to the surface, and the IR camera measures the thermal response. The heat modulation frequency is adjusted to optimize the depth of defect detection.
- **Defect Detection:** The phase lag between the applied heat and the thermal response is measured, with defects altering the phase and amplitude of the thermal waves.



Advantages:

- High sensitivity to deeper defects compared to pulse thermography.
- Excellent signal-to-noise ratio.

Limitations:

- Time-consuming compared to pulse thermography.
- Requires precise control of heat modulation.

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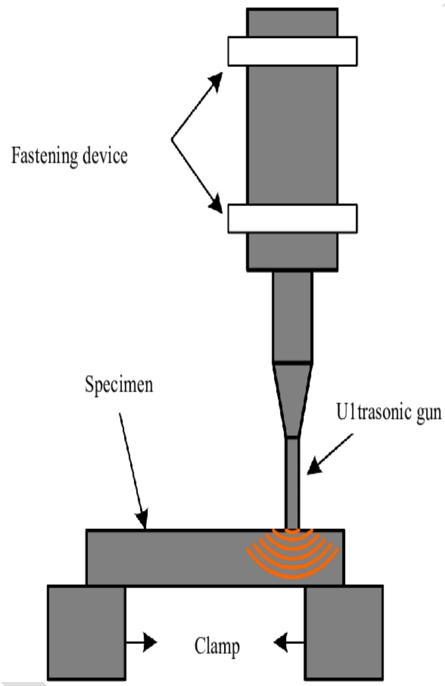
iii. Vibrothermography (or Sonic Thermography):

- **Process:** Ultrasound or mechanical vibrations are applied to the object, generating frictional heat at defects such as cracks or delaminations. The heat generated at the defect sites is detected by the IR camera.
- **Defect Detection:** Defects heat up faster due to friction, making them stand out on the thermogram.



Advantages:

- Particularly effective for detecting cracks and delaminations.
- No need for external heat sources like lamps.

Limitations:

- Requires ultrasonic or vibration equipment.
- Not effective for all types of materials.

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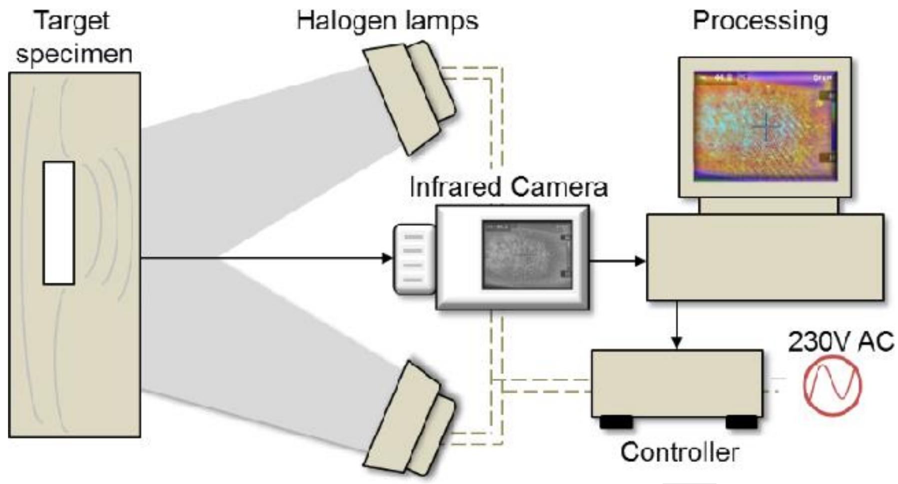
iv. Transient Thermography:

- **Process:** A continuous heat source (e.g., a halogen lamp or laser) is applied to the object, and the IR camera records the transient heat flow over time.
- **Defect Detection:** The thermal gradient created during heating reveals defects, especially when monitoring the cooling process.



Advantages:

- Can be used for both shallow and deep defect detection, depending on heating duration.
- Versatile, suitable for various materials.

Limitations:

- Longer inspection times than pulse thermography.
- Requires precise control of heating.

Comparison of Active Thermography Methods

Method	Heat Source	Detection Depth	Speed	Best For
Pulse Thermography	Flash Lamp, Laser	Shallow (few mm)	Very Fast	Surface and near-surface defects
Lock-in Thermography	Periodic Heat Source	Deeper (few cm)	Medium	Detecting deeper defects
Vibrothermography	Ultrasonic Vibration	Surface & Subsurface	Medium to Fast	Crack detection, delaminations
Transient Thermography	Continuous Heat	Shallow or Deep	Medium to Slow	Versatile for various defect depths

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Applications of Thermography Inspection:

1. **Electrical Systems:** Detecting hotspots, faulty connections, or overloaded circuits.
2. **Building Inspection:** Identifying heat loss, moisture intrusion, or insulation defects.
3. **Aerospace:** Checking for delaminations, debonds, and other structural defects in composites.
4. **Automotive:** Monitoring engines, exhaust systems, and electrical systems for overheating or defects.
5. **Pipeline Monitoring:** Detecting corrosion under insulation or cracks in pipe surfaces.

3. **What is Eddy current testing? Explain the principle with a neat sketch and discuss the different types of coil arrangements used in eddy current testing.**

Eddy Current Testing (ECT)

Eddy Current Testing (ECT) is a non-destructive testing (NDT) method primarily used to detect surface and near-surface flaws in conductive materials. This method is based on the principle of electromagnetic induction and is commonly used to inspect metals for defects such as cracks, corrosion, and thickness variations.

Principle of Eddy Current Testing

When an alternating current (AC) flows through a coil (probe), it generates an alternating magnetic field. If this coil is brought close to a conductive material (e.g., a metal), the alternating magnetic field induces circulating currents in the material called **eddy currents**.

These eddy currents generate their own magnetic field, which opposes the magnetic field of the coil. The magnitude and distribution of these eddy currents depend on the properties of the material, such as conductivity, permeability, and the presence of flaws (like cracks, voids, or corrosion). Any disturbance in the eddy current flow (due to a defect) will cause a change in the impedance (resistance and inductive reactance) of the coil, which can be measured and analyzed.

Steps Involved in Eddy Current Testing:

1. An AC current is passed through the coil, generating a magnetic field.
2. The coil is brought near the conductive material, inducing eddy currents in the material.
3. Defects in the material disturb the eddy currents, changing the coil's impedance.
4. The impedance change is measured and displayed, indicating the presence of defects.

Sketch of Eddy Current Testing Principle

The following is a simple sketch illustrating the principle of ECT:

```
(Eddy Current Testing Sketch)

 +----------------+
 |                |    Coil (with AC current)
 |      Coil      |   ---------------
 |                |   |             |
 +----------------+   | Magnetic Field
                       |             |
                       |             |
                      ---------------
                             ↓
      Conductive Material   → → → Eddy Currents
                       ↑
                       |
                  Flaw (e.g., Crack or Corrosion)
                       ↓
```

Coil Arrangements in Eddy Current Testing

Different coil arrangements are used in ECT depending on the type of inspection required (e.g., surface, subsurface, or complex geometries). The coil configuration determines how the eddy currents are induced in the material and how the impedance changes are measured.

Here are the common coil arrangements used in ECT:

1. Absolute Coils:

- **Design:** A single coil is used to induce eddy currents and measure the changes in impedance due to defects.
- **Working:** The absolute coil measures the overall impedance, which can change due to the presence of a flaw, material thickness, or conductivity variations.
- **Application:** Typically used for detecting surface and near-surface defects in flat or curved surfaces.

Advantages:

- Simple to use and interpret.
- Suitable for detecting general flaws and material variations.

Limitations:

- Sensitive to lift-off variations (distance between the probe and the material).
- Requires baseline calibration for accurate results.

---

2. Differential Coils:

- **Design:** Two coils are arranged either side-by-side or one above the other. These coils are connected such that their signals are compared (differentiated) in real-time.
- **Working:** Both coils measure impedance simultaneously, and the difference in their readings is recorded. This eliminates the background noise and highlights any localized defects.
- **Application:** Commonly used for detecting small, localized flaws like cracks or corrosion, especially in complex geometries.

Advantages:

- Excellent for detecting small, localized defects.
- Minimizes noise from variations in material thickness or lift-off effects.

Limitations:

- More complex than absolute coils.
- Difficult to use for measuring gradual changes in material properties (e.g., wall thinning).

---

3. Reflection (or Transmit-Receive) Coils:

- **Design:** One coil acts as a transmitter (generating the eddy currents), while the other acts as a receiver (measuring the eddy current response).

- **Working:** The transmitter coil induces eddy currents in the material, and the receiver coil measures the disturbance in the magnetic field due to any defects.
- **Application:** Used for subsurface flaw detection and in applications where direct access to both sides of the material is available.

Advantages:

- More sensitive to deep defects.
- Effective in detecting subsurface flaws.

Limitations:

- Requires proper alignment between the transmitter and receiver coils.
- More complex than absolute and differential arrangements.

---

4. Encircling Coils:

- **Design:** A coil or multiple coils encircle the entire circumference of cylindrical objects (e.g., pipes or rods).
- **Working:** As the object passes through the coil, eddy currents are induced throughout its circumference, and defects cause changes in the coil impedance.
- **Application:** Typically used for the inspection of cylindrical objects, such as pipes, rods, and wires.

Advantages:

- Capable of inspecting the entire circumference of cylindrical objects in one pass.
- High throughput for inline inspection processes.

Limitations:

- Limited to cylindrical geometries.
- Less sensitive to very small flaws compared to differential coils.

---

5. Probe Coils (Surface Probes):

- **Design:** Small, handheld probes are equipped with coils that are positioned very close to the surface of the material being tested.
- **Working:** The probe is scanned over the surface, and eddy currents are induced in the material. Surface and near-surface flaws cause changes in the impedance of the coil, which are recorded.
- **Application:** Used for inspecting flat and curved surfaces, especially for detecting surface cracks, weld inspections, and corrosion detection.

Advantages:

- Easy to maneuver over complex surfaces.
- Highly sensitive to surface flaws.

Limitations:

- Limited penetration depth (mostly surface and near-surface defects).
- Sensitive to lift-off variations.

Applications of Eddy Current Testing:

- **Surface Crack Detection:** Ideal for detecting surface cracks in conductive materials, particularly in welds, fasteners, or stress-prone areas.
- **Corrosion Detection:** ECT is used for detecting corrosion in aircraft components, pipes, and other metal structures.
- **Thickness Measurement:** Eddy currents can be used to measure material thickness and detect thinning due to wear or corrosion.
- **Heat Treatment Verification:** It can check the effectiveness of heat treatment processes by measuring changes in the material's electrical conductivity.

4. **Explain the Principle of Thermography process and its advantages and disadvantages with neat sketch**

Thermography Process: Principle, Advantages, and Disadvantages

Thermography, also known as **Infrared (IR) Thermography**, is a non-destructive testing (NDT) method that detects thermal radiation emitted by an object's surface to visualize temperature differences. These variations in temperature can reveal hidden defects, like cracks, voids, delaminations, or areas of corrosion, in various materials and structures.

Principle of Thermography

Thermography operates based on the principle that **all objects with a temperature above absolute zero (-273.15°C or 0 Kelvin) emit infrared radiation**. The amount of radiation emitted is proportional to the temperature of the object. An infrared (IR) camera detects this radiation and converts it into a visual image known as a **thermogram**, where different colors or shades of gray represent different temperatures.

Working Principle:

1. An **infrared camera** is used to detect thermal radiation from the surface of an object.
2. The camera captures infrared energy and converts it into a digital signal.
3. This signal is processed by software to generate a **thermogram** (heat map), where areas of different temperatures appear as different colors.
    - **Hot areas** may indicate high temperature regions, possibly due to stress or friction.
    - **Cold areas** may indicate voids, cracks, or other defects.
4. By analyzing the thermal image, defects or areas of concern in the object can be identified.

The principle of **thermal contrast** is key to thermography:

- Areas with different thermal properties (e.g., cracks, voids) will heat up and cool down at different rates compared to the surrounding material.
- These temperature differences appear on the thermogram, making it possible to locate defects.

Neat Sketch of Thermography Process

Here is a conceptual diagram of the thermography process:

```
+---------------------+         +---------------------+
|     Infrared Camera |         |   Thermographic Image|
|    (Captures IR)    |         |      (Thermogram)    |
+---------------------+         +---------------------+
          |
          |
  Infrared Radiation (IR)
          |
+---------------------+
|                     |
|   Test Object       | <---- Defect (e.g., Crack, Void)
|  (Emits Heat)       |
+---------------------+
```

Types of Thermography:

1. **Passive Thermography:**
    - Detects the naturally occurring heat patterns from an object.
    - Used for equipment already generating heat (e.g., electrical components, running machinery).
2. **Active Thermography:**
    - External heat is applied to the object to create a thermal gradient.
    - Used when the object does not emit sufficient heat by itself, such as for inspecting composites or detecting subsurface defects.

Advantages of Thermography

1. **Non-contact and Non-destructive:**
    - Thermography does not require physical contact with the object, making it ideal for inspecting hot or inaccessible components without interrupting operations.
2. **Wide Area Inspection:**
    - Thermography can inspect large areas quickly, making it useful for monitoring large structures (e.g., buildings, airplanes, electrical panels).
3. **Real-time Imaging:**
    - The thermogram is generated in real-time, providing instant feedback and allowing for quick decision-making.
4. **Sensitive to Small Temperature Changes:**
    - Thermography cameras can detect very small temperature differences, making it sensitive to even subtle defects.
5. **Detects Both Surface and Subsurface Defects:**
    - In active thermography, subsurface defects such as delaminations, cracks, or voids can be identified through variations in heat flow.
6. **Versatile Application:**
    - Thermography is used in a wide range of industries, including aerospace, electrical maintenance, mechanical inspection, and building diagnostics.

Disadvantages of Thermography

1. **Limited to Surface and Near-Surface Defects:**

- In passive thermography, the technique is mostly effective for surface-level defects. Deeper defects are harder to detect unless active thermography techniques are used.

2. **Dependent on Thermal Properties:**
   - Thermography relies on differences in thermal properties, so defects that do not significantly affect heat flow (e.g., some types of inclusions) may not be detected.
3. **Environmental Influence:**
   - Environmental conditions like wind, rain, or sunlight can affect temperature readings and lead to inaccurate results. Careful control of environmental factors is required for accurate measurements.
4. **Expensive Equipment:**
   - High-resolution infrared cameras and analysis software are costly, which may be a limiting factor for some applications or organizations.
5. **Surface Preparation Needed:**
   - For some applications, surface conditions (e.g., dirt, paint, insulation) may interfere with accurate thermal readings, requiring surface cleaning or preparation before testing.
6. **Training Required:**
   - Operators must be trained to interpret thermograms correctly and differentiate between real defects and temperature variations caused by other factors.

Applications of Thermography:

1. **Electrical Systems:** Detecting overheating in circuits, transformers, and connections.
2. **Building Inspections:** Identifying heat loss, insulation failures, moisture ingress, and air leaks.
3. **Mechanical Systems:** Monitoring wear, friction, and misalignment in bearings, motors, and pumps.
4. **Aerospace and Automotive:** Detecting delaminations in composite structures and assessing heat distribution in engines and exhaust systems.
5. **Medical:** Detecting abnormal body heat patterns for medical diagnostics, such as inflammation or tumors.

5. **Discuss in detail about the Contact and non contact inspection Methods in Thermography with neat sketches.**

Contact and Non-contact Inspection Methods in Thermography

Thermography, the process of detecting temperature variations in objects by capturing infrared radiation, can be performed using both **contact** and **non-contact** inspection methods. The difference between these two approaches lies in how the temperature of the object is measured and detected. Each method has its specific applications, advantages, and limitations.

---

1. Contact Inspection Methods in Thermography

In **contact thermography**, sensors are physically placed in contact with the object being tested to measure the temperature directly. This method is generally used in cases where infrared radiation cannot be effectively captured or where precise temperature measurements are needed.

a. Thermocouples and Resistance Temperature Detectors (RTDs):

- **Thermocouples** and **RTDs** are commonly used contact temperature sensors. These sensors are attached directly to the surface of the material being tested.

- **Working Principle:**
    - **Thermocouples** work based on the thermoelectric effect, where a voltage is generated at the junction of two dissimilar metals that is proportional to the temperature.
    - **RTDs** work by measuring the resistance of a material, which changes with temperature.
- **Application:** Contact methods are used in industries requiring direct temperature measurements, such as in furnaces, kilns, or in medical diagnostics for skin temperature measurement.

Sketch of Contact Inspection Method:

```
      +--------------------+
      |                    |    Thermocouple/RTD
      | Contact Sensor     |   (Measures Temperature)
      +--------------------+
                |
                |
   +-------------------------+
   |       Test Object       |
   |                         |
   +-------------------------+
```

Advantages of Contact Thermography:

1. **Highly Accurate:** Direct contact with the surface provides precise temperature readings.
2. **Effective for Low-Emissivity Materials:** Materials that do not emit much infrared radiation, such as shiny metals, can be measured accurately.
3. **Suitable for Long-term Monitoring:** Can be used for continuous temperature measurement over extended periods.

Disadvantages of Contact Thermography:

1. **Invasive:** Physical contact with the object may disturb sensitive surfaces or alter the heat distribution.
2. **Limited to Surface Measurements:** Only measures the temperature at the point of contact, making it less useful for detecting subsurface defects.
3. **Slow Process:** The sensor needs to be physically placed on the surface, which can be time-consuming in large or complex structures.

---

2. Non-contact Inspection Methods in Thermography

In **non-contact thermography**, the temperature is measured remotely using infrared (IR) cameras. These cameras detect the infrared radiation naturally emitted by objects and generate a thermogram (heat map) that visually represents temperature variations.

a. Infrared Thermography (Passive and Active):

- **Infrared Cameras:** The key tool in non-contact thermography is the infrared camera, which captures the infrared radiation emitted by the object.
- **Types of Non-contact Thermography:**
    - **Passive Thermography:** The infrared camera detects naturally emitted radiation without applying external heat. This is ideal for equipment or objects that are naturally hot during operation, such as electrical circuits or mechanical equipment.
    - **Active Thermography:** External heat is applied to the object (using flash lamps, lasers, etc.), and the infrared camera monitors the thermal response. Active thermography is used to detect subsurface defects by observing how heat dissipates from the material.

Sketch of Non-contact Inspection Method (Infrared Thermography):

```
 +-----------------------+
 |   Infrared Camera     |    Captures Infrared Radiation
 +-----------------------+     (Generates Thermogram)
           |
           |
     Infrared Radiation (IR)
           |
  +---------------------------+
  |      Test Object          |
  |     (Emitting Heat)       |
  +---------------------------+
```

Advantages of Non-contact Thermography:

1. **Non-invasive:** No physical contact with the object, making it ideal for inspecting sensitive surfaces or high-temperature equipment.
2. **Large Area Coverage:** The infrared camera can inspect large areas quickly, making it ideal for real-time monitoring of large structures like buildings, pipelines, and electrical systems.
3. **Detects Subsurface Defects (with Active Thermography):** Active thermography can reveal subsurface defects such as cracks, voids, or delaminations.
4. **Remote Monitoring:** Allows for temperature measurements from a distance, useful in hazardous or hard-to-reach areas.

Disadvantages of Non-contact Thermography:

1. **Depends on Emissivity:** The accuracy of temperature measurement depends on the emissivity of the material. Low-emissivity materials (like shiny metals) may give inaccurate readings unless properly calibrated.
2. **Influenced by Environmental Factors:** Factors like wind, humidity, or reflections can affect the accuracy of the measurements.
3. **Limited Penetration Depth:** While active thermography can detect subsurface defects, the depth of detection is limited compared to other NDT methods like ultrasound or radiography.

Comparison of Contact and Non-contact Thermography:

Aspect	Contact Thermography	Non-contact Thermography
Measurement Technique	Direct contact with the surface	Remote sensing using infrared radiation
Sensor	Thermocouples, RTDs	Infrared cameras
Accuracy	Highly accurate	Accurate, but depends on material emissivity
Surface Impact	May disturb sensitive surfaces	No physical impact on the object

Aspect	Contact Thermography	Non-contact Thermography
Area Coverage	Point measurements (localized)	Wide area coverage in one scan
Subsurface Defects	Not detectable	Detectable with active thermography
Speed of Measurement	Slower, as sensors must be attached	Fast, real-time image capture
Applications	Precision temperature measurement	Large-scale inspection, real-time monitoring

---

Applications of Non-contact Thermography:

- **Electrical Inspections:** Detecting overheating in electrical circuits, motors, and transformers.
- **Mechanical Systems:** Monitoring bearings, motors, and pumps for signs of wear, friction, or misalignment.
- **Building Inspections:** Identifying heat loss, insulation defects, and moisture intrusion in walls, roofs, and windows.
- **Aerospace and Automotive Industries:** Inspecting composites for delaminations, cracks, or impact damage.
- **Medical Applications:** Detecting abnormal temperature patterns in the human body for diagnostic purposes (e.g., inflammation or tumors).

6. **Enumerate the various probes used in EDT with details and sketches.**

Various Probes Used in Eddy Current Testing (ECT)

In **Eddy Current Testing (ECT)**, different types of probes are used depending on the application, the material being tested, and the type of defect to be detected. Each probe has a specific design to generate and measure eddy currents effectively in various situations, such as surface, subsurface, and complex geometries.

Here is an overview of the commonly used **ECT probes**:

---

1. Surface Probes

Surface probes are the most commonly used probes in ECT. These probes are designed to inspect the surface and near-surface areas of conductive materials. They are highly sensitive to cracks, corrosion, and other defects on the surface.

Types of Surface Probes:

- **Pencil Probe:**
  - **Design:** Small, handheld probes resembling a pencil, with a coil at the tip.
  - **Application:** Used for detecting surface cracks in metals, particularly in welds, bolts, and flat or curved surfaces.
- **Advantages:** Highly sensitive to surface defects.
- **Limitations:** Limited penetration depth; can only detect near-surface flaws.

Sketch of a Pencil Probe:

```
+------------------+
| Probe Handle     |
+------------------+
```

```
             |
             |     Coil
    +-------------------+
    |      Coil Tip     |   (Placed near material surface)
    +-------------------+
```

---

2. Encircling (Bobbin) Probes

Encircling probes, also known as **bobbin probes**, are designed to surround the entire circumference of cylindrical objects such as pipes, rods, or wires. These probes are used for fast, full-coverage inspections of tubular components.

Design:

- The probe has a coil that is shaped like a bobbin, which surrounds the test object.

Application:

- Typically used in the inspection of cylindrical objects like heat exchanger tubes, pipelines, and rods to detect corrosion, cracks, and thinning.

Advantages:

- Inspects the entire circumference of a cylindrical object in one pass.
- High inspection speed for tubular materials.

Limitations:

- Limited to cylindrical geometries.
- Less sensitive to small, localized defects compared to other probes.

Sketch of Encircling Probe:

```
      +------------------------------+
      |  Encircling Coil (Bobbin)   |   Probe fits around the tube
      +------------------------------+
                   |
       +---------------------------+
       |     Tube (Test Object)    |
       +---------------------------+
```

---

3. Differential Probes

Differential probes are equipped with two or more coils arranged side by side. These coils measure the difference in eddy current response between two points, making them particularly sensitive to small, localized defects.

Design:

- Two coils connected in opposition (differential arrangement) to detect changes in impedance between them.

Application:

- Commonly used for detecting small surface cracks or pitting corrosion, especially in areas with varying geometry (e.g., welds, bolt holes).

Advantages:

- Highly sensitive to small, localized defects.
- Reduces noise caused by lift-off and other surface variations.

Limitations:

- Limited to detecting small defects and not suitable for gradual changes in material properties.

Sketch of Differential Probe:

```
+---------------------+
|    Coil 1           |
+---------------------+
            |
            |
+---------------------+
|    Coil 2           |    (Both coils detect variations)
+---------------------+
```

---

4. Reflection (or Transmit-Receive) Probes

In **reflection probes**, there are separate transmitting and receiving coils. The transmitting coil generates eddy currents, while the receiving coil measures the magnetic field disturbance caused by defects in the material.

Design:

- One coil acts as a transmitter, and the second coil acts as a receiver.

Application:

- Ideal for inspecting both surface and subsurface defects, particularly in cases where direct access to the material's surface is limited (e.g., through coatings or coverings).

Advantages:

- Can detect subsurface flaws.
- More sensitive to deep defects compared to single-coil surface probes.

Limitations:

- More complex alignment required between transmitter and receiver coils.
- Limited effectiveness if the coils are not properly aligned.

Sketch of Reflection Probe:

```
+---------------------+
|    Transmitting Coil|
+---------------------+    (Generates Eddy Currents)
         |
         |
+---------------------+
|    Receiving Coil   |    (Measures disturbance caused by defects)
+---------------------+
```

---

5. Array Probes

Array probes are more advanced probes that contain multiple coils in a specific configuration to simultaneously scan a larger area. These probes can cover more surface area compared to single-coil probes, improving the inspection speed and allowing for more comprehensive detection of flaws.

Design:

- Multiple coils arranged in an array, each generating and measuring eddy currents in the material.

Application:

- Commonly used for scanning large surfaces or complex geometries, such as aircraft structures or large welded joints.

Advantages:

- Faster inspection of larger areas.
- Provides detailed mapping of defect locations and sizes.

Limitations:

- Expensive and more complex than simpler probes.
- Requires advanced data processing and interpretation.

Sketch of Array Probe:

```
+-----------------------------------+
| Array of Multiple Coils           |    (Each coil covers a different area)
+-----------------------------------+
```

---

6. Rotary Probes

Rotary probes are designed to rotate while inspecting cylindrical or rounded holes, such as bolt holes. The probe rotates to provide 360-degree coverage of the area, making it ideal for detecting cracks and other defects in difficult-to-reach areas.

Design:

- The probe rotates as it scans the inside of a cylindrical hole or around a round object.

Application:

- Used in the inspection of fastener holes, boreholes, and other cylindrical geometries, especially in the aerospace industry for detecting cracks near bolt holes.

Advantages:

- Provides complete 360-degree coverage in a single pass.
- Highly effective for detecting cracks in difficult-to-access areas.

Limitations:

- More complex mechanical setup due to the rotary mechanism.
- Limited to cylindrical or circular features.

Sketch of Rotary Probe:

```
 +-------------------------+
 |   Rotary Mechanism      |
 +-------------------------+    (Probe rotates inside the hole)
               |
               |
 +---------------------+
 |    Probe Coil       |
 +---------------------+
```

---

7. Weld Probes

Weld probes are specialized probes designed to inspect welds, where defects like cracks, porosity, or lack of fusion commonly occur. These probes are shaped to fit the geometry of the weld and provide focused eddy current testing in the weld region.

Design:

- Shaped to match the contours of weld seams, with coils oriented to detect defects along and across the weld.

Application:

- Used specifically for weld inspections in pipelines, pressure vessels, and structural steel components.

Advantages:

- Customizable shapes to fit different weld geometries.
- Focused detection of weld defects.

Limitations:

- Limited to weld areas and less suitable for general surface inspection.

Sketch of Weld Probe:

```
    +---------------------+
    |  Weld Probe         |  (Custom Shape for weld geometry)
    +---------------------+
            |
            |
```

```
    +-------------------------+
    |  Weld Area (Test Object)|
    +-------------------------+
```

Summary of Probes Used in Eddy Current Testing

Probe Type	Application	Advantages	Limitations
Surface Probe	Surface and near-surface crack detection	Sensitive to surface flaws	Limited penetration depth
Encircling (Bobbin) Probe	Full circumference of cylindrical objects	Full coverage in one pass	Limited to cylindrical geometries
Differential Probe	Small, localized defects in varying geometries	Reduces noise, highly sensitive	Limited to small flaws
Reflection Probe	Surface and subsurface defect detection	Sensitive to subsurface defects	Complex alignment required
Array Probe	Large surface area scanning	Fast, detailed inspection	Expensive and complex
Rotary Probe	Inspection of cylindrical holes	360-degree coverage	Mechanically complex
Weld Probe	Focused inspection of welds	Customized for welds	Limited to weld areas

UNIT IV ULTRASONIC TESTING & AET

Ultrasonic Testing: Types of ultrasonic waves, characteristics, attenuation, couplants, probes, EMAT. Inspection methods-pulse echo, transmission and phased array techniques, types of scanning and displays, angle beam inspection of welds, time of flight diffraction (TOFD) technique, Thickness determination by ultrasonic method, Study of A, B and C scan presentations, calibration. Acoustic Emission Technique – Introduction, Types of AE signal, AE wave propagation, Source location, Kaiser effect, AE transducers, Principle, AE parameters, AE instrumentation, Advantages & Limitations, Interpretation of Results, Applications.

PART - A (2 MARKS)

1. **Name the standard calibration Blocks used in UST. [AM2018]**

Ultrasonic calibration blocks

- V1 Ultrasonic Calibration Block.
- V2 Ultrasonic Calibration Block.
- Step Calibration Block.
- KMT-176 M2 Set of the Ultrasonic Plane-Parallel Thickness Standards (KUSOT-180)
- Welds testing calibration blocks with notches.
- AS2083 Calibration Block (IOW Type 2 Block)

2. **Give the properties of Acoustic Waves. [AM2018]**

Sound waves, or acoustic waves, are mechanical waves that travel through media (air, water, solids) due to object vibrations, characterized by frequency, amplitude, wavelength, and speed. These waves can be longitudinal or transverse, depending on the direction of particle displacement relative to wave propagation.

3. **Name the type of ultrasonic transducers used in ultrasonic testing. [AM2019]**

- Contact transducers: Directly touch the test material for inspection.
- Angle beam transducers: Produce ultrasonic waves at an angle to access internal features like welds.
- Immersion transducers: Used in a water bath to inspect materials.
- Delay line transducers: Utilize a delay line to improve near-surface resolution.
- Dual element transducers: Have separate elements for transmitting and receiving ultrasonic waves, enhancing signal clarity.

4. **What is the principle of testing in acoustic emission test? [AM2019]**

The principle of acoustic emission testing (AET) is that when a material's stress fields are redistributed, elastic waves are generated within the material. These waves can be detected and analyzed to identify defects in the material

5. **What type of transducers is preferred for low ultrasonic frequencies? [AM2017]**

For low ultrasonic frequencies, curvilinear (convex) transducers are typically preferred, as they are designed to produce a wider beam with deeper penetration, which is ideal for low-frequency applications; often used in medical ultrasound imaging for deep tissue examination.

6. **Depth of penetration of Ultrasonic waves decreases as the frequency Ultrasonic waves increases. Comment.[AM2017]**

The statement "Depth of penetration of Ultrasonic waves decreases as the frequency of Ultrasonic waves increases" is true; as the frequency of an ultrasonic wave rises, its penetration depth reduces because higher frequencies are more readily absorbed by the medium, resulting in less energy reaching deeper tissues

7. **What is the difference between straight beam and angle beam detectors.[ND2018]**

While straight beam transducers are generally the best for defects like delamination in components like plates and hanger pins, angle beam transducers are accurate for pipes and tubing where flaws are at an angle to the test material surface.

8. **What are the sources of Acoustic Emission? [ND2018]**

The sources of AE are initiation/growth of cracks, yielding, failure of bonds, fibre failure, delamination in composites, etc. Most of the sources of AEs are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure.

9. **What is the significance of couplant in ultrasonic testing? [ND2021]**

A couplant is a material (usually liquid) that facilitates the transmission of ultrasonic energy from the transducer into the test specimen. Couplant is generally necessary because the acoustic impedance mismatch between air and solids (i.e. such as the test specimen) is large.

10. **List the different modes of ultrasonic waves. [ND2021]**

Based on particle displacement of the media, ultrasonic waves are classified into four types or modes: (i) Longitudinal or Compressional or Pressure ultrasonic Waves. In the longitudinal waves particles of medium vibrate back and forth parallel to the direction of propagation of wave.

11. **What are the advantages of pulse echo technique over transmission technique in UT? [ND2020]**

In the pulse echo method, the sound is transmitted and received by the same transducer. Thus, it is an excellent method when there is access to only one side of the part. The amplitude of the echo received from the back surface is reduced by the presence of defects in the structure.

12. **What do you understand by acoustic emission? [ND2020]**

Acoustic emission (AE) is the phenomenon of radiation of acoustic (elastic) waves in solids that occurs when a material undergoes irreversible changes in its internal structure, for example as a result of crack formation or plastic deformation due to aging, temperature gradients, or external mechanical forces.

PART - B & C (13MARKS)

1. **Explain various components involved in ultrasonic testing equipment with block diagram.**

Ultrasonic Testing (UT) Equipment: Components and Block Diagram

Ultrasonic Testing (UT) is a widely used non-destructive testing (NDT) technique that uses high-frequency sound waves to detect flaws in materials, measure thickness, and characterize materials. Ultrasonic waves are transmitted into the material, and the reflections from internal structures or defects are captured and analyzed. The key components of ultrasonic testing equipment play critical roles in generating, transmitting, receiving, and analyzing these ultrasonic signals.

---

1. Components of Ultrasonic Testing Equipment

1.1. Pulser/Receiver

- **Pulser:** The pulser is responsible for generating short-duration high-voltage electrical pulses, which are then converted into ultrasonic waves by the transducer. These pulses are typically in the range of 1 to 15 MHz, depending on the material and the application.
- **Receiver:** After the ultrasonic waves interact with the material and reflect from flaws or boundaries, the receiver captures these signals. The receiver amplifies the returning ultrasonic waves and converts them back into electrical signals for further processing.

1.2. Transducer (Probe)

- The **transducer** is the key component that converts electrical pulses into mechanical ultrasonic waves and vice versa. It consists of piezoelectric crystals that vibrate when subjected to an electrical signal, generating ultrasonic waves. When ultrasonic waves return after interacting with flaws, the transducer converts these mechanical vibrations back into electrical signals.
- **Types of Transducers:**
  - **Contact Transducers:** Used in direct contact with the material's surface.
  - **Immersion Transducers:** Used in a water or coupling medium to inspect materials without direct contact.
  - **Angle Beam Transducers:** Used to introduce angled waves into the material for inspecting welds or angled surfaces.

1.3. Couplant

- A **couplant** is a medium (gel, oil, water) applied between the transducer and the material being tested. Its purpose is to eliminate the air gap and ensure efficient transmission of ultrasonic waves from the transducer into the material. Ultrasonic waves cannot travel effectively through air, so the couplant ensures proper acoustic coupling.

1.4. Display/Monitor

- The **display unit** visually presents the data collected from the ultrasonic waves. This could be in the form of an oscilloscope, digital display, or a graphical interface.
  - **A-scan:** A basic waveform representation of the reflected signals (amplitude vs. time).
  - **B-scan:** A two-dimensional cross-sectional image of the material.
  - **C-scan:** A top-view image showing the plan view of the material and defect locations.

1.5. Clock/Timer

- The **clock/timer** measures the time taken for ultrasonic waves to travel through the material, reflect from a boundary or flaw, and return to the transducer. This time-of-flight measurement is used to calculate the material's thickness or the distance to a defect.

1.6. Amplifier

- The **amplifier** boosts the weak signals received from the transducer to a measurable level. Since the reflected ultrasonic waves can be weak after traveling through the material and encountering flaws, the amplifier makes the signal strong enough for processing and display.

1.7. Analog-to-Digital Converter (ADC)

- In modern ultrasonic testing systems, the **ADC** converts the analog signal received from the transducer into a digital signal that can be further processed by the microcontroller or computer system for more advanced analysis.

1.8. Data Acquisition System (Processing Unit)

- The **processing unit** interprets the received digital signals and determines the presence, size, and location of defects. Advanced UT systems may use digital signal processing techniques to filter noise and improve accuracy. This data is then sent to the display for visualization.

Block Diagram of Ultrasonic Testing Equipment:

```
          +------------------+
          |   Pulser/        |
          |   Receiver        |
          +---------+--------+
                    |
                    |
                    V
          +------------------+
          |    Transducer     |
          +------------------+
                    |
                    |
     (Ultrasonic Waves Into Material)
                    |
                    V
   +-----------------+    +-------------------+
   |    Material      |    |      Couplant      |  (Eliminates Air Gap)
   +-----------------+    +-------------------+
                    |
                    |
      (Reflected Waves Back to Transducer)
                    |
                    V
         +------------------+
         |    Amplifier      |
         +---------+--------+
                    |
                    |
                    V
   +---------------------------+
   |   Analog-to-Digital       |  (Converts to Digital Signal)
   |   Converter (ADC)         |
   +---------------------------+
                    |
                    |
                    V
   +----------------------------+
   |   Processing Unit          |  (Processes Data)
   +----------------------------+
                    |
                    |
                    V
     +----------------------------+
     |    Display/Monitor          |  (Shows A-scan, B-scan, C-scan, etc.)
     +----------------------------+
```

2. Explanation of the Process

1. **Pulser:** The pulser sends high-voltage electrical pulses to the transducer.
2. **Transducer:** The transducer converts the electrical pulse into high-frequency ultrasonic waves and sends them into the material being inspected. The same transducer also receives the reflected ultrasonic waves.
3. **Couplant:** Ensures proper transmission of ultrasonic waves from the transducer to the material by eliminating air gaps.
4. **Material Interaction:** Ultrasonic waves travel through the material and are either reflected by internal flaws (such as cracks, voids, or inclusions) or the back wall of the material.
5. **Returning Signals:** Reflected ultrasonic waves return to the transducer, which converts the mechanical waves back into electrical signals.
6. **Amplifier:** The returning signals are often weak and are amplified to measurable levels.
7. **Analog-to-Digital Conversion:** The analog signals are converted into digital signals for further processing.
8. **Processing Unit:** The processing unit interprets the signals to detect flaws, determine their size, and locate their position. Advanced algorithms may also filter noise and improve accuracy.
9. **Display/Monitor:** The final result is displayed on the screen in the form of A-scan (waveform), B-scan (cross-sectional image), or C-scan (top-view image) depending on the type of inspection.

---

3. Advantages of Ultrasonic Testing:

- **High Penetration Power:** Can detect deep flaws in thick materials.
- **High Sensitivity:** Capable of detecting small and subsurface defects.
- **Immediate Results:** Provides real-time feedback during testing.
- **Non-destructive:** Does not damage the material during testing.
- **Versatile:** Can be used for flaw detection, material characterization, and thickness measurement.

---

4. Disadvantages of Ultrasonic Testing:

- **Requires Skilled Technicians:** Interpretation of results can be complex.
- **Surface Preparation Needed:** Surface must be clean and smooth, and a couplant is required.
- **Limited to Certain Materials:** Ultrasonic testing is less effective on rough, uneven, or irregular surfaces and in highly attenuating materials like plastics or rubbers.

2. **Discuss about the time of flight diffraction and phased array techniques of ultrasonic testing with neat figures?**

Time of Flight Diffraction (TOFD) and Phased Array Ultrasonic Testing (PAUT)

Both **Time of Flight Diffraction (TOFD)** and **Phased Array Ultrasonic Testing (PAUT)** are advanced non-destructive testing (NDT) techniques used for detecting flaws in materials. These methods provide detailed information about the location, size, and nature of defects within a structure. Let’s discuss each technique in detail along with relevant diagrams.

---

1. Time of Flight Diffraction (TOFD)

Principle of TOFD:

TOFD is based on the diffraction of ultrasonic waves at the edges of a flaw or defect. When an ultrasonic pulse encounters a flaw, such as a crack, part of the sound wave is diffracted from the tips of the defect, allowing the precise location of the defect to be determined. TOFD uses both longitudinal and shear waves for this purpose.

How TOFD Works:

- **Transmitter and Receiver:** In TOFD, two probes are placed on opposite sides of the test material — one acting as a transmitter (emitting ultrasonic waves) and the other as a receiver.
  - The **transmitter** emits ultrasonic pulses, and the **receiver** detects waves that have diffracted off the edges of any defects in the material.
- **Time of Flight Measurement:** The key parameter in TOFD is the time it takes for the diffracted sound wave to travel from the defect to the receiver. This time is referred to as the **time of flight**. By analyzing the time of flight of the diffracted waves, the exact location and size of a defect can be determined with high accuracy.

Advantages of TOFD:

- **High Accuracy:** TOFD provides precise information about the depth and size of defects.
- **Full Volume Coverage:** It can inspect the full thickness of a material in a single pass.
- **High Sensitivity to Cracks:** Excellent for detecting cracks, particularly in welds.

Limitations of TOFD:

- **Limited to Crack Detection:** TOFD is primarily used for detecting crack-like defects; it may not detect small, volumetric defects effectively.
- **Dead Zone:** There is a small zone near the surface where TOFD cannot detect flaws due to the proximity of the transmitter and receiver.

Sketch of TOFD:

```
+--------------------------------+
|                                |
|          Material              |
|                                |
|       (Defect/Crack)           |
|      ^                  ^     |
|      |   Diffracted     |     |
|      |   Waves          |     |
|      ^                  ^     |
|      |                  |     |
+--------------------------------+
      Transmitter   Receiver
  (Emitting Pulses)   (Receiving Diffracted Waves)
```

In the diagram, the ultrasonic waves are emitted by the **transmitter** and diffract at the edges of the crack. The diffracted waves are then detected by the **receiver**, allowing the calculation of the crack location and size.

---

2. Phased Array Ultrasonic Testing (PAUT)

Principle of PAUT:

Phased Array Ultrasonic Testing (PAUT) uses multiple small ultrasonic elements arranged in an array. By varying the timing (phasing) of the electrical pulses sent to each element, the direction and focus of the ultrasonic beam can be electronically controlled. This makes PAUT highly versatile, enabling inspectors to inspect complex geometries and detect flaws at various angles.

How PAUT Works:

- **Array of Transducers:** The PAUT probe consists of multiple small piezoelectric transducer elements arranged in a linear or matrix configuration.
- **Beam Steering:** By adjusting the timing of electrical pulses sent to each element, the direction of the sound beam can be controlled. This allows the beam to be steered at various angles, eliminating the need for physical movement of the probe.
- **Beam Focusing:** By altering the timing of pulses across the elements, the ultrasonic beam can also be focused at different depths within the material, enhancing the detection of defects at varying depths.
- **Multiple Scans:** PAUT can generate multiple scan types, including **sectorial scans (S-scan)** and **linear scans (L-scan)**, providing real-time images of the internal structure of the material.

Advantages of PAUT:

- **High Flexibility:** Can inspect complex geometries and adjust angles without physically moving the probe.
- **Real-Time Imaging:** Provides detailed, real-time images (A-scan, B-scan, and C-scan).
- **High Sensitivity:** Can detect both surface and subsurface defects.

Limitations of PAUT:

- **Complex Equipment:** More complex and expensive than conventional ultrasonic testing.
- **Requires Skilled Operators:** Proper interpretation of PAUT data requires skilled technicians and advanced software.

Sketch of Phased Array Ultrasonic Testing (PAUT):

```
+--------------------------------+
|                                |
|          Material              |
|                                |
|        (Defect/Flaw)           |
|                                |
+--------------------------------+
        ^        ^         ^
       / \      / \       / \
      /   \    /   \     /   \
     /     \  /     \   /     \
  Transducer Array Elements (Beam Steering and Focusing)
```

In PAUT, multiple transducer elements are used to steer and focus the ultrasonic beam, allowing for the inspection of defects at various angles and depths.

Comparison Between TOFD and PAUT:

Feature	TOFD	PAUT
Principle	Diffraction of ultrasonic waves at flaws	Beam steering and focusing using phased elements
Key Function	Precise depth and size of cracks	Flexible angle inspections and real-time imaging
Sensitivity	Highly sensitive to crack-like defects	Sensitive to both surface and subsurface flaws
Inspection Area	Typically used for welds and cracks	Can inspect complex geometries and various materials
Imaging Capability	Limited imaging (A-scan)	Provides A-scan, B-scan, and C-scan images
Advantages	High accuracy, precise flaw detection	High flexibility, real-time imaging, multiple angles
Limitations	Limited to crack detection, dead zones	Complex equipment, requires skilled operators

3. **Explain the different scan modes of ultrasonic testing. Discuss the use of UT to inspect porosity/cavity in materials.**

Different Scan Modes of Ultrasonic Testing (UT)

Ultrasonic testing (UT) utilizes different scan modes to visualize and detect flaws in materials. Each scan mode provides a unique view of the internal structure of the material and is suited for specific inspection needs. The most common scan modes in UT are **A-scan**, **B-scan**, **C-scan**, and **S-scan (sector scan)**.

---

1. A-Scan (Amplitude Scan)

Principle:

- **A-scan** is a one-dimensional display where the horizontal axis represents **time** (or distance in the material) and the vertical axis represents the **amplitude** of the received echo signals.
- It is the simplest form of ultrasonic display and shows only the time it takes for ultrasonic pulses to return after reflection from a flaw or boundary.

Uses:

- Commonly used to measure the **thickness** of materials or detect defects in simple geometries.
- Provides information on the **depth** of a flaw but does not offer a clear image of the flaw's shape or size.

Sketch:

```
Amplitude (Y-axis)
```

```
^
|
|         /\         /\
|        /  \       /  \
|_______/____\_____/____\_______> Time (X-axis)
       (Back wall)    (Defect)
```

---

2. B-Scan (Brightness Scan or Cross-Sectional Scan)

Principle:

- **B-scan** is a two-dimensional representation that provides a cross-sectional image of the inspected material.
- The horizontal axis represents the **probe movement** (or scanning distance), while the vertical axis represents the **depth** of the flaw or material boundaries.

Uses:

- Ideal for detecting and sizing **defects** in welds, joints, and other critical areas.
- Provides a better understanding of the **size** and **shape** of defects compared to A-scan.

Sketch:

```
B-Scan Display (Cross-Sectional View)

Probe Movement (X-axis) ------>
  +---------------------------+
  |                           |
  |       Defect/Flaw         |
  |          /\               |
  |         /  \              |
  |        /    \             |
  |________\____/_____________|
        Depth (Y-axis)
```

---

3. C-Scan (Planar or Top View Scan)

Principle:

- **C-scan** produces a top-view or plan-view image of the material, giving a 2D image where the x-axis and y-axis represent the **position of the probe** and the **material surface**.
- It provides a detailed map of the inspected area, with color coding or shading indicating the **intensity** or **depth** of the signals.

Uses:

- Commonly used for **corrosion mapping**, **bond testing**, and inspecting large, flat areas like aircraft skins or large sheets of metal.
- Provides a clear picture of the **location** and **extent** of defects.

Sketch:

```
C-Scan Display (Top View)
```

```
+----------------------------+
|                            |
|       Defect Area          |
|                            |
+----------------------------+
  Probe Position (X and Y Axis)
```

---

4. S-Scan (Sector Scan)

Principle:

- **S-scan** or **Sector Scan** is primarily used in **Phased Array Ultrasonic Testing (PAUT)**.
- It displays ultrasonic data in a fan-shaped or sectoral view. By using multiple angles of the ultrasonic beam, it provides a cross-sectional image similar to B-scan but with more **coverage**.

Uses:

- Excellent for inspecting **welds** and **complex geometries** where defects can occur at different angles.
- Allows the inspection of a large area without moving the probe, making it more efficient.

Sketch:

```
S-Scan Display (Fan-Shaped View)

+------------------------------+
|        Defect                |
|          /\                  |
|         /  \                 |
|        /    \                |
|       /      \               |
|______/_\______/_\____________|
     Sector View (Multiple Angles)
```

Ultrasonic Testing to Inspect Porosity/Cavity in Materials

Porosity and **cavities** are internal defects in materials that can weaken structural integrity. Ultrasonic testing can be highly effective in identifying and characterizing these types of discontinuities.

How UT Detects Porosity/Cavity:

1. **Pulse Echo Mode:**
   - In this mode, a transducer emits an ultrasonic pulse that travels through the material. If the pulse encounters a **porosity** or **cavity**, some of the sound energy will reflect back to the transducer earlier than expected due to the presence of air or gas-filled voids.
   - The **time of flight** and **amplitude** of the reflected echo help identify the presence of porosity.
2. **Through-Transmission Mode:**
   - A transducer on one side of the material sends ultrasonic waves through the material, and a receiver on the opposite side captures the transmitted sound.

    - If porosity or a cavity is present, the ultrasonic signal will be **scattered** or **weakened**, resulting in a significant drop in the signal received by the receiver.
3. **Time of Flight Diffraction (TOFD):**
    - TOFD is particularly useful for detecting and sizing large cavities and porosity. The diffracted waves from the edges of voids are captured and analyzed to determine the extent and location of the defects.
4. **Phased Array Ultrasonic Testing (PAUT):**
    - PAUT provides highly detailed, real-time images of porosity and cavities. By electronically steering the ultrasonic beam, the inspection can be done from multiple angles, giving a comprehensive understanding of the size, shape, and distribution of the porosity.

Advantages of Using UT for Porosity Detection:

- **Non-Destructive:** No damage to the material.
- **Highly Sensitive:** Can detect small voids and distributed porosity within materials.
- **Real-Time Feedback:** Immediate results, particularly with PAUT.
- **Accurate Sizing:** Provides accurate information on the size and extent of porosity.

Limitations:

- **Surface Preparation:** UT requires a good surface condition and a couplant to transmit sound waves effectively.
- **Limited in Complex Shapes:** In areas with complex geometries, it may be challenging to position the transducer for optimal results.

4. **What is ultrasonic Testing? Draw the schematic diagram with three methods of Scanning (A-scan, B-scan, and C-scan) with neat sketch.**

Ultrasonic Testing (UT)

Ultrasonic Testing (UT) is a non-destructive testing (NDT) method that uses high-frequency sound waves to detect flaws or discontinuities in materials, measure material thickness, and evaluate structural integrity. The method involves transmitting ultrasonic waves into a material and analyzing the reflected sound waves to detect internal flaws like cracks, porosity, or cavities.

In UT, an ultrasonic transducer generates sound waves, which propagate through the material. Any internal defect or material boundary reflects the sound waves, and the transducer detects these echoes. The time taken for the echoes to return and their amplitude is used to determine the location, size, and orientation of defects.

Basic Principle of Ultrasonic Testing:

1. **Generation of Ultrasonic Waves:** A transducer generates high-frequency ultrasonic pulses.
2. **Propagation:** The ultrasonic waves travel through the material.

3. **Reflection:** When the waves encounter a boundary or flaw (such as a crack or void), they reflect back to the transducer.
4. **Detection:** The reflected waves are analyzed to determine the nature of the flaw (size, location, etc.).

Schematic Diagram of Ultrasonic Testing:

A basic schematic of ultrasonic testing equipment consists of:

- **Transducer:** Emits and receives ultrasonic waves.
- **Pulser/Receiver:** Generates electrical pulses to drive the transducer.
- **Display Unit:** Visualizes the echoes received from the material (A-scan, B-scan, C-scan).

```
+----------------------------------+
|  Ultrasonic Testing Equipment    |
|                                  |
|  [Pulser/Receiver]               |
|         |                        |
|         V                        |
|  [Transducer]                    |
|         |                        |
|  Ultrasonic Waves (Sound)        |
|         |                        |
|     [Material]                   |
|                                  |
|  Echo Reflections from Flaw      |
|         |                        |
|     [Display Unit]               |
+----------------------------------+
```

Three Methods of Scanning in Ultrasonic Testing

1. **A-Scan (Amplitude Scan)**
   - **A-Scan** is the simplest type of ultrasonic scan.
   - It displays the amplitude of the reflected ultrasonic waves as a function of time.
   - The **horizontal axis** represents time (or distance in the material), while the **vertical axis** shows the amplitude of the reflected signal.
   - Provides basic information about the **depth** and **location** of flaws but not the shape.

   A-Scan Schematic:

```
Amplitude (Y-axis)
^
|
|        /\         /\          /\
|       /  \       /  \        /  \
|______/____\_____/____\______/____\___> Time (X-axis)
     Back Wall      Flaw     Back Wall
```

---

2. **B-Scan (Brightness Scan or Cross-Sectional Scan)**
   - **B-Scan** is a two-dimensional representation that provides a cross-sectional image of the material.

- The **vertical axis** represents depth, and the **horizontal axis** represents the scan distance or position of the probe.
- Offers a view of the **location**, **size**, and **shape** of the flaw but not the extent of the flaw along the width.

B-Scan Schematic:

```
B-Scan Display (Cross-Sectional View)

Probe Movement (X-axis) ------>
  +---------------------------+
  |                           |
  |          Flaw             |
  |            /\             |
  |           /  \            |
  |          /    \           |
  |__________\____/___________|
      Depth (Y-axis)
```

---

3. **C-Scan (Planar or Top View Scan)**
    - **C-Scan** provides a plan view (top view) of the material, showing the extent of a defect along the surface.
    - The **x-axis** and **y-axis** represent the scan position (probe movement), and the color intensity or shading shows the **thickness** or **signal amplitude**.
    - Used to generate a **map** of defects, commonly applied in corrosion mapping or large surface areas like aircraft panels.

C-Scan Schematic:

```
C-Scan Display (Top View)

 +---------------------------+
 |                           |
 |         Defect Area        |
 |                           |
 +---------------------------+
   Probe Position (X and Y Axis)
```

Applications of Ultrasonic Testing (UT):

- **Flaw Detection:** Cracks, voids, and inclusions in metals and composites.
- **Thickness Measurement:** Corrosion monitoring in pipelines and storage tanks.
- **Weld Inspection:** Detecting weld defects like cracks, porosity, or incomplete fusion.
- **Bond Testing:** Inspection of adhesive and composite bonds.

Advantages of Ultrasonic Testing:

- **Non-destructive:** No damage to the material.
- **High Penetration Depth:** Can inspect thick materials.
- **High Sensitivity:** Detects even small defects.
- **Real-time Results:** Immediate feedback during inspections.

Limitations:

- **Requires Skilled Operator:** Interpretation of results requires expertise.

- **Surface Preparation Needed:** A couplant (gel) is required to transmit ultrasonic waves.
- **Limited for Complex Geometries:** Some complex shapes may be difficult to inspect.

5. **With neat sketch explain the Working Principle of Acoustic Emission Process.**

Acoustic Emission (AE) Process

Acoustic Emission (AE) is a non-destructive testing (NDT) technique used to monitor and analyze transient elastic waves generated by the rapid release of energy from localized sources within a material. These sources can be due to phenomena such as crack formation, corrosion, or material deformation. AE is particularly valuable for monitoring ongoing processes and detecting flaws in real-time.

Working Principle of Acoustic Emission:

1. **Generation of Acoustic Emission:**
   - **Source of Emission:** Acoustic emissions are generated when materials undergo rapid changes, such as crack propagation, plastic deformation, or phase transformations. These changes release elastic waves into the material.
   - **Types of Sources:** Common sources include crack growth, corrosion, fiber breakage in composites, and other material instabilities.
2. **Propagation of Acoustic Waves:**
   - **Elastic Waves:** The emitted waves, called **acoustic emission signals**, travel through the material. These are typically high-frequency (30 kHz to several MHz) stress waves.
   - **Wave Behavior:** The waves propagate through the material and are affected by factors such as material properties, geometric configuration, and the nature of the source.
3. **Detection of Acoustic Emission:**
   - **Sensors:** Acoustic emission sensors (usually piezoelectric transducers) are placed on the surface of the material. These sensors pick up the high-frequency acoustic waves.
   - **Signal Capture:** The sensors convert the acoustic waves into electrical signals, which are then amplified and processed.
4. **Analysis and Interpretation:**
   - **Data Processing:** The captured signals are analyzed to determine the location, type, and intensity of the emission sources. This may involve techniques like time-of-flight measurements, waveform analysis, and source location triangulation.
   - **Real-Time Monitoring:** AE allows for real-time monitoring of structural integrity, providing immediate feedback on the material's condition.

Schematic Diagram of Acoustic Emission Process:

```
+-----------------------------------------+
|            Acoustic Emission Process    |
|                                         |
|    +-------------+       +-------------+   |
|    |  Source of  |       |  Material   |   |
|    |  Emission   |       |  Structure  |   |
|    | (e.g., Crack)|------>|             |   |
|    |             |       +-------------+   |
|    |             |                         |
|    +-------------+                         |
|              |                             |
|              |  (Acoustic Waves)           |
|              |                             |
|    +--------------------+      +--------------------+
```

```
|     |      Acoustic        |       |     Signal Analysis  |
|     |      Emission        |       |     and Processing   |
|     |      Sensors         |       |                      |
|     |  (Piezoelectric)     |       |                      |
|     +----------------------+       +----------------------+
|         (Detects AE signals)         (Interprets data)
|                                              |
+----------------------------------------------+
```

Explanation of the Diagram:

1. **Source of Emission:**
    - The source of acoustic emission can be a material undergoing stress, such as a developing crack or deformation. This source generates high-frequency elastic waves due to the release of energy.
2. **Material Structure:**
    - The acoustic waves propagate through the material structure, interacting with it and reflecting or refracting based on material properties and the type of flaw.
3. **Acoustic Emission Sensors:**
    - These sensors, usually piezoelectric transducers, are attached to the material's surface. They detect the acoustic waves generated by the emission source.
4. **Signal Analysis and Processing:**
    - The detected signals are amplified and analyzed to determine characteristics such as the location, type, and severity of the emission. This information is used to assess the material's condition and integrity.

Advantages of Acoustic Emission:

- **Real-Time Monitoring:** Provides continuous, real-time monitoring of material conditions.
- **Sensitive to Active Flaws:** Detects active and growing defects, such as cracks and delaminations.
- **Global Inspection:** Can monitor large structures and components without needing to inspect each area individually.
- **Early Detection:** Capable of identifying potential failures before they become critical.

Limitations of Acoustic Emission:

- **Requires Calibration:** Sensors and equipment need to be properly calibrated for accurate results.
- **Signal Interpretation:** Interpretation of AE signals can be complex and may require skilled operators.
- **Surface Accessibility:** Sensors need to be attached to the material's surface, which may be challenging for complex or inaccessible geometries.

6. **Explain the principle of Acoustic Emission technique, Discuss about the various parameters involved in AET.**

Principle of Acoustic Emission (AE) Technique

Acoustic Emission (AE) is a non-destructive testing (NDT) technique that involves monitoring and analyzing transient elastic waves generated by sudden, localized releases of energy within a material. These emissions can be caused by various phenomena such as crack propagation, material deformation, or corrosion. AE is used to assess the condition of structures and materials in real-time by detecting and analyzing the acoustic signals generated by these processes.

Principle of Acoustic Emission:

1. **Generation of Acoustic Emission:**
    - **Source of Emission:** Acoustic emissions are generated by rapid, localized events within the material. Common sources include:
        - **Crack Formation:** When a crack propagates, it generates stress waves.
        - **Plastic Deformation:** Material deformation can release energy as acoustic waves.
        - **Phase Changes:** Changes in the material's phase (e.g., solid to liquid) can also cause AE.
    - **Energy Release:** The sudden release of energy from these events produces high-frequency elastic waves that travel through the material.
2. **Propagation of Acoustic Waves:**
    - **Elastic Waves:** The waves generated are typically high-frequency (30 kHz to several MHz) stress waves that propagate through the material.
    - **Wave Behavior:** The behavior of these waves depends on the material properties, the nature of the source, and the geometry of the structure.
3. **Detection of Acoustic Emission:**
    - **Sensors:** Acoustic emission sensors, often piezoelectric transducers, are attached to the surface of the material. These sensors pick up the high-frequency acoustic waves and convert them into electrical signals.
    - **Signal Processing:** The electrical signals are amplified, filtered, and analyzed to determine the characteristics of the emission source.
4. **Analysis and Interpretation:**
    - **Data Analysis:** The processed signals are analyzed to determine the source, location, and severity of the emission. Techniques such as time-of-flight calculations and waveform analysis are used.
    - **Monitoring:** AE allows for continuous monitoring of the material or structure, providing real-time feedback on its condition.

Parameters Involved in Acoustic Emission Technique

1. **Amplitude:**
    - **Definition:** The amplitude of an acoustic emission signal refers to the strength or magnitude of the detected signal. It is often indicative of the energy released during the emission event.
    - **Importance:** Higher amplitude signals generally suggest more significant or intense events, such as large cracks or major deformation.
2. **Frequency:**
    - **Definition:** The frequency of an acoustic emission signal represents the number of oscillations per second (Hz) of the acoustic wave.
    - **Importance:** Different emission sources produce signals at varying frequencies. Analyzing the frequency spectrum can help identify the type of emission source.
3. **Duration:**
    - **Definition:** Duration is the time interval over which an acoustic emission signal is detected.
    - **Importance:** The duration can provide insights into the nature of the emission source. For example, long-duration signals may indicate continuous or ongoing processes, while short bursts may suggest sudden, localized events.
4. **Rise Time:**
    - **Definition:** Rise time is the time it takes for the signal to go from a baseline level to its peak amplitude.

   - **Importance:** A short rise time often indicates a rapid release of energy, such as crack initiation, whereas a longer rise time might suggest more gradual events.
5. **Time of Flight:**
   - **Definition:** Time of flight is the time it takes for the acoustic emission signal to travel from the source to the sensor.
   - **Importance:** By measuring the time of flight, the location of the emission source within the material can be estimated using triangulation techniques.
6. **Count Rate:**
   - **Definition:** Count rate refers to the number of acoustic emission events detected per unit time.
   - **Importance:** A high count rate can indicate active defect formation or growth, while a low count rate may suggest stable material conditions.
7. **Source Location:**
   - **Definition:** The position of the emission source within the material or structure.
   - **Importance:** Accurate location of the source helps in assessing the impact of the emission event on the material’s overall integrity.
8. **Waveform Shape:**
   - **Definition:** The shape of the acoustic emission signal waveform, including its rise time, amplitude envelope, and decay.
   - **Importance:** The waveform shape can provide information about the type of emission event and the material's response.

Schematic Diagram of Acoustic Emission Process:

```
+---------------------------------------------------+
|               Acoustic Emission Monitoring        |
|                                                   |
|  +-----------------+                              |
|  |  Emission Source|   -----> (Acoustic Waves)    |
|  +-----------------+                              |
|          |                                        |
|          | (Waves propagate through material)     |
|          V                                        |
|    +-------------------------+                    |
|    |  Material Structure     |                    |
|    +-------------------------+                    |
|          |                                        |
|          | (Acoustic Waves detected)              |
|          V                                        |
|    +-------------------------+                    |
|    |  Acoustic Emission      |                    |
|    |  Sensors (Piezoelectric)|                    |
|    +-------------------------+                    |
|          |                                        |
|          | (Signals converted to electrical data)|
|          V                                        |
|    +-------------------------+                    |
|    |  Signal Processing and  |                    |
|    |  Analysis                |                   |
|    +-------------------------+                    |
|          |                                        |
|          | (Data interpretation and reporting)    |
|          V                                        |
```

```
|     +-------------------------+                     |
|     |  Data Interpretation    |                     |
|     |  and Reporting          |                     |
|     +-------------------------+                     |
+-----------------------------------------------------+
```

7. **Enumerate the different ways of representing the data in Ultrasonic Inspection. Explain in detail.**

In Ultrasonic Inspection (UT), various methods are used to represent the data obtained from ultrasonic signals. Each method provides different types of information about the material being inspected, and the choice of representation depends on the specific requirements of the inspection. Here are the different ways of representing data in ultrasonic inspection:

1. A-Scan (Amplitude Scan)

Description:

- **A-Scan** is a one-dimensional graphical representation that displays the amplitude of ultrasonic echoes as a function of time (or distance).
- The horizontal axis represents time (or depth in the material), and the vertical axis represents the amplitude of the returned echo signal.

Detailed Explanation:

- **Amplitude:** The height of the peaks on the A-scan trace indicates the strength of the reflected signals, which can be used to identify the presence and relative size of defects.
- **Time of Flight:** The horizontal axis shows the time it takes for the ultrasonic pulse to travel to a reflector and back. This can be converted to distance based on the known speed of sound in the material.

Use:

- **Thickness Measurement:** Determine the thickness of materials by measuring the time between the initial pulse and the echo from the back wall.
- **Flaw Detection:** Identify the presence and depth of flaws by analyzing the location and amplitude of peaks.

Sketch:

```
Amplitude (Y-axis)
^
|
|        /\        /\
|       /  \      /  \
|______/____\____/____\_______> Time (X-axis)
      (Back wall)   (Defect)
```

---

2. B-Scan (Brightness Scan or Cross-Sectional Scan)

Description:

- **B-Scan** provides a two-dimensional cross-sectional view of the material.
- The vertical axis represents depth (distance from the surface), and the horizontal axis represents the position of the probe as it scans across the material.

Detailed Explanation:

- **Depth Profile:** Shows how the material's structure changes with depth and can highlight features such as flaws and interfaces.
- **Cross-Sectional View:** Provides a view of the material's internal structure along a specific path.

Use:

- **Flaw Sizing:** Determine the size, shape, and location of defects within the material.
- **Structure Analysis:** Examine internal structures such as welds, laminations, or corrosion.

Sketch:

```
B-Scan Display (Cross-Sectional View)

Probe Movement (X-axis) ------>
  +-----------------------------+
  |                             |
  |       Defect/Flaw           |
  |          /\                 |
  |         /  \                |
  |        /    \               |
  |________\____/_______________|
        Depth (Y-axis)
```

---

3. C-Scan (Planar or Top View Scan)

Description:

- **C-Scan** provides a two-dimensional top view (planar view) of the inspected area.
- Both the x-axis and y-axis represent the scan position, and the intensity or color of the image represents the thickness or signal amplitude.

Detailed Explanation:

- **Surface Map:** Creates a map of the surface or a cross-section of the material, showing variations in thickness or signal strength.
- **Color Coding:** Often uses color or shading to represent the magnitude of the reflected signal or the depth of features.

Use:

- **Corrosion Mapping:** Visualize and quantify corrosion or thinning across large areas.
- **Bond Testing:** Inspect adhesive bonds and composite structures for uniformity and voids.

Sketch:

```
C-Scan Display (Top View)

 +------------------------------+
 |                              |
 |       Defect Area            |
 |                              |
 +------------------------------+
   Probe Position (X and Y Axis)
```

---

4. S-Scan (Sector Scan)

Description:
S-Scan (Sector Scan) is typically used in Phased Array Ultrasonic Testing (PAUT) and provides a fan-shaped or sectoral view of the material.
It represents a cross-sectional view by electronically steering the beam from multiple angles.
Detailed Explanation:
Sector View: Shows the inspection area from multiple angles, allowing for a comprehensive view of defects within a sector.
Dynamic Imaging: Offers real-time imaging and is often used for complex geometries or weld inspections.
Use:
Weld Inspection: Evaluate the integrity of welds from various angles.
Complex Geometries: Inspect parts with complex shapes or configurations.

Sketch:

```
S-Scan Display (Fan-Shaped View)

+------------------------------+
|          Defect              |
|            /\                |
|           /  \               |
|          /    \              |
|         /      \             |
|________/________\___________|
     Sector View (Multiple Angles)
```

---

5. D-Scan (Depth Scan)

Description:
D-Scan provides a depth view of a material, often used in conjunction with other scans to analyze specific layers or regions.
Detailed Explanation:
Depth Profile: Shows detailed depth information and is useful for analyzing specific features or defects at different depths.
Use:
Layer Analysis: Examine individual layers within composite materials or coatings.

Sketch:

```
D-Scan Display (Depth View)

 +------------------------------+
 |      Depth Profile           |
 |                              |
 |   Defect Layer               |
 |       /\                     |
 |      /  \                    |
 |_____/____\___________________|
       Depth (Y-axis)
```

---

6. T-Scan (Time Scan)

Description:
T-Scan represents ultrasonic data over time, showing how the signal changes as a function of time.
Detailed Explanation:
Temporal Analysis: Useful for monitoring changes in signal characteristics over time, especially in dynamic or evolving conditions.
Use:
Real-Time Monitoring: Track changes in material properties or defect behavior over time.

Sketch:

```
T-Scan Display (Time View)

+-----------------------------+
|     Signal over Time        |
|                             |
|      /\     /\              |
|     /  \   /  \             |
|___/____\/____\______________|
       Time (X-axis)
```


UNIT V RADIOGRAPHY TESTING

Sources-X-rays and Gamma rays and their characteristics-absorption, scattering. Filters and screens, Imaging modalities-film radiography and digital radiography (Computed, Direct, Real Time, CT scan). Problems in shadow formation, exposure factors, inverse square law, exposure charts, Penetrameters, safety in radiography.

<u>PART - A (2 MARKS)</u>

1. **Give the Properties of X-Rays and Gamma rays. [AM2018]**
   X-rays and gamma rays are both forms of high-energy electromagnetic radiation with short wavelengths, meaning they can penetrate matter and are invisible to the human eye; they travel in straight lines at the speed of light, cannot be deflected by electric or magnetic fields, and have the ability to ionize matter, potentially damaging living cells; the key difference is that gamma rays originate from the nucleus of an atom while X-rays are produced by electron interactions outside the nucleus, making gamma rays generally more energetic and penetrating than X-rays.

2. **What is intensifying Screens? [AM2018]**
   An intensifying screen is a thin sheet of material that's used in X-ray cassettes to convert X-ray energy into light and expose film. The screen is placed in close contact with the film to increase the effect of the X-ray beam on the film and reduce image degradation.

3. **What are the applications of radiography test? [AM2019]**
   Radiography testing has many applications, including:

   - Detecting internal flaws
     Radiography can detect internal cracks, corrosion, pitting, blockages, and casting defects in a variety of materials, including metal, plastic, and metal alloys.
   - Checking composition variations

Radiography can detect significant variations in composition.

- Quality control in welded joints
  Radiography can inspect welds for defects like porosity or incomplete fusion.
- Gas turbine repair
  Radiography can check for internal crack formation and cooling-hole clearance or connections.
- Medical diagnosis
  Radiography can screen for abnormalities or injuries, assist in diagnosing diseases, and track the body's reaction to treatment.

4. **What are the functions of filters and screens in X-ray radiography? [AM2019]**
   In X-ray radiography, filters are used to selectively absorb low-energy X-rays from the beam, reducing unnecessary radiation exposure to the patient while improving image quality by removing scatter, while screens, typically called intensifying screens, convert the X-ray beam into visible light to expose the film and create the image with a lower radiation dose required.

5. **Compare and contrast radiography testing with ultrasonic testing [AM2019]**
   The difference between radiography and ultrasonic testing is that radiography provides a direct image of internal defects using radiation, whereas ultrasonic testing uses sound waves to infer the presence of defects based on wave reflections.

6. **How does computer Tomography differers from other Imaging Techniques? [AM2017]**
   Computed Tomography (CT) differs from other imaging techniques by providing significantly more detailed, cross-sectional views of the body through the use of multiple X-ray beams taken from various angles, allowing for 3D reconstruction of internal structures, unlike standard X-rays which only provide a 2D image; this makes CT particularly useful for identifying complex fractures, internal bleeding, and tumors, while exposing patients to a higher level of radiation compared to other imaging methods like MR

7. **Differentiate between film and filmless technique in Radiography. [ND2018]**
   Digital radiography (computed radiography) replaces the screen/film system of conventional radiographic techniques by processing image data in digital (computer) rather than analog form. The essential parts of a digital radiography system are the image plate and the image reader.

8. **State inverse square law in Radiography. [ND2018]**
   The inverse square law in radiography states that the intensity of radiation decreases as the square of the distance from the source increases. For example, if you double the distance from the source, the intensity of radiation will decrease by a factor of four

9. **What is need for exposure chart in radiography? [ND2021]**
   A good quality exposure chart is one of the most important tools to help you achieve high quality radiographs and reduce the number of repeated X-rays that you take.

10. **What is film contrast in radiography testing? [ND2021]**
    Film contrast in radiography is the difference in darkness between areas of a radiographic image. It's caused by the different ways that materials with varying thickness absorb

radiation. Thicker areas appear lighter than thinner areas on the film.

11. **What is film density in radiography? Give expression for film density.**

In radiography, "film density" refers to a measure of how dark a film appears after exposure and processing, essentially indicating the level of blackness on the image, and is calculated as the logarithm of the ratio of incident light intensity to transmitted light intensity through the film; mathematically expressed as: $D = \log(I0/It)$, where D is film density, I0 is the intensity of incident light, and It is the intensity of transmitted light through the film

12. **What do you mean by computed tomography?**

Computed tomography, or CT, is a diagnostic imaging procedure that uses X-rays and a computer to create cross-sectional images of the body. The images are taken from different angles and used to create 3D views of tissues and organs

PART - B & C (13MARKS)

1. **Brief write about the following phenomena during interaction of X-ray with matter:**
   (i) **Photoelectric effect**
   (ii) **Compton scattering**
   (iii) **Pair production and**
   (iv) **Thomson scattering**

(i) Photoelectric Effect:

The **photoelectric effect** occurs when an X-ray photon is absorbed by an electron in an atom, providing enough energy to eject the electron from its orbit. The energy of the incoming photon is transferred to the electron, and any energy remaining after overcoming the binding energy of the electron is given to the electron as kinetic energy. This effect is more likely to occur in materials with higher atomic numbers and for lower-energy X-rays.

Key points:

- The X-ray photon is completely absorbed.
- An electron is ejected from the atom (called a photoelectron).
- The probability of occurrence decreases with increasing photon energy.

(ii) Compton Scattering:

Compton scattering occurs when an X-ray photon interacts with a loosely bound outer electron. The photon transfers part of its energy to the electron, causing the electron to be ejected (a "Compton electron"), and the photon itself is scattered with reduced energy and a longer wavelength. This process is more common with medium-energy X-rays.

Key points:

- The photon is scattered with reduced energy.
- An electron is ejected.
- The scattering angle depends on the energy of the photon.

(iii) Pair Production:

Pair production happens when an X-ray photon with energy greater than 1.02 MeV passes near a nucleus and is converted into an electron and a positron (the antimatter counterpart of the electron). This process can only occur if the energy of the photon exceeds the combined rest mass energy of the electron and positron.

Key points:

- Occurs with very high-energy photons (greater than 1.02 MeV).
- The photon is annihilated, creating an electron-positron pair.
- The energy is shared between the electron, positron, and the nucleus.

(iv) Thomson Scattering:

Thomson scattering is the elastic scattering of low-energy X-rays by free or loosely bound electrons. In this process, the energy and wavelength of the X-ray photon remain unchanged, but the photon changes its direction. It is a low-energy limit of Compton scattering, where the photon energy is much smaller than the electron rest mass energy.

Key points:

- No energy loss by the photon.
- The photon is scattered in a different direction.
- Typically occurs with low-energy X-rays.

These phenomena describe the various ways X-rays interact with matter, depending on the energy of the incoming photons and the type of material involved.

2. **How computed radiography differs from conventional radiography? Briefly write about the principle of operation of computed radiography with neat sketch.**

Differences Between Computed Radiography (CR) and Conventional Radiography (Film-based Radiography):

Aspect	Conventional Radiography	Computed Radiography (CR)
Image Capture	Uses X-ray film to capture images.	Uses a reusable imaging plate (Photostimulable

Aspect	Conventional Radiography	Computed Radiography (CR)
Medium		Phosphor plate - PSP).
Image Processing	Chemical processing of film is required to develop the image.	Digital image processing with no need for chemical development.
Image Review	Images are viewed on physical film sheets.	Images are digitized and viewed on computer screens.
Storage	Physical storage of films is required.	Digital storage, retrieval, and transmission of images (PACS systems).
Time for Results	Longer time due to film processing.	Quicker results as image acquisition is immediate after scanning.
Radiation Dose	Higher radiation dose may be required to get a clear image.	Potential for lower radiation doses with optimized imaging techniques.
Image Enhancement	No digital image enhancement is possible.	Digital images can be enhanced, magnified, or processed for better quality.
Reusability	X-ray film is single-use.	Imaging plates in CR are reusable multiple times before replacement.

Principle of Operation of Computed Radiography (CR):

1. Exposure:

- The patient is exposed to X-rays, similar to conventional radiography. However, instead of film, a **Photostimulable Phosphor (PSP) plate** is used to capture the image.
- When the X-rays strike the PSP plate, the plate absorbs and stores the energy of the X-rays as a latent image.

2. Plate Scanning:

- The exposed PSP plate is taken to a **CR reader**, where it is scanned by a laser beam.
- The laser stimulates the phosphor material, causing it to emit light proportional to the amount of absorbed X-ray energy.

3. Image Formation:

- The emitted light is captured by a **photodetector** and converted into an electrical signal. This signal is digitized to create a digital image.

4. Erasing the Plate:

- After scanning, the residual image on the plate is erased by exposure to a bright white light, allowing the plate to be reused for the next X-ray.

5. Image Processing:

- The digitized image can be enhanced, adjusted for brightness and contrast, magnified, and archived in a **Picture Archiving and Communication System (PACS)** for easy retrieval.

Neat Sketch of Computed Radiography (CR) System:

Here's a basic representation of the workflow in a Computed Radiography system:

X-ray Tube ——► Patient ——► PSP Plate ——► CR Reader ——► Digital Image

(Latent Image Stored) (Laser Scan, Light Emission, Digitization)

This diagram shows the sequential process from X-ray exposure to digital image acquisition, making computed radiography a flexible and faster imaging modality compared to conventional film-based methods.

3. **Explain the classification of X-ray films used in industrial radiography. Discuss briefly the construction of X-ray film with simple line diagram.**

Classification of X-ray Films in Industrial Radiography:

X-ray films used in industrial radiography are classified based on their **speed**, **grain size**, and **contrast**. These factors determine the film's ability to detect defects, resolution, and sensitivity to X-rays.

1. Based on Film Speed:

- **Slow-Speed Films**:
  - High-resolution films with fine grain size.
  - Used for detecting minute defects with excellent detail.
  - Require a higher X-ray exposure (longer exposure time).
  - Applications: Critical inspections like aerospace parts or welds.
- **Medium-Speed Films**:
  - Offer a balance between resolution and speed.
  - Moderate grain size, providing good sensitivity and adequate image detail.
  - Applications: General industrial applications and defect detection in castings or medium-thickness materials.
- **High-Speed Films**:
  - Low-resolution films with coarse grain size.
  - Sensitive to X-rays and require less exposure time.
  - Used for thick or dense materials where resolution is less critical.
  - Applications: Inspection of large metal components or thick materials.

2. Based on Film Contrast:

- **High-Contrast Films**:
  - Offer high density between different areas of the film, providing excellent defect detection in materials with fine structural details.
  - Preferred when sharp images are required.
- **Low-Contrast Films**:
  - Have lower density differences and are suitable for less detailed inspections.
  - Used when the material has large, uniform features.

3. Based on Grain Size:

- **Fine Grain Films**:
  - These films provide high image quality and resolution.
  - Best for detecting small discontinuities and precise inspection.
- **Coarse Grain Films**:
  - Lower resolution and used for inspections where fine detail is less important.

Construction of X-ray Film:

An X-ray film consists of multiple layers designed to capture and display the image formed by X-rays passing through an object. The basic layers are:

1. **Base**:
   - The base is the foundation of the film, typically made of **polyester** or **cellulose acetate**.
   - It provides physical support to the film and is usually transparent or lightly tinted.
2. **Emulsion Layer**:
   - The emulsion layer contains **silver halide crystals** (usually silver bromide), suspended in gelatin.
   - This layer is sensitive to X-rays and visible light. When X-rays interact with the emulsion, they cause chemical changes in the silver halide crystals, creating a latent image that is developed during film processing.
3. **Adhesive Layer**:
   - A thin adhesive layer binds the emulsion to the base, ensuring stability and durability during handling and processing.
4. **Protective Coating (Overcoat)**:
   - A thin, transparent layer of gelatin or other material protects the emulsion from mechanical damage, scratches, and environmental factors during handling.

Simple Line Diagram of X-ray Film Construction:

```
| Protective Coating (Overcoat)   |
| Emulsion Layer (Silver Halide)  |
| Adhesive Layer                  |
| Polyester Base                  |
```

```
| Adhesive Layer                 |
| Emulsion Layer (Silver Halide)  |
| Protective Coating (Overcoat)   |
```

This diagram shows a **double-emulsion film** (used for greater sensitivity), where emulsion layers are applied on both sides of the polyester base for enhanced image capture. Each emulsion layer is protected by a coating that guards against physical damage.

4. **Describe the following (i) Fluoroscopy and (ii) Xeroradiography.**

(i) Fluoroscopy:

Fluoroscopy is an imaging technique that uses X-rays to produce real-time, dynamic images of internal structures in the body or industrial components. Unlike traditional radiography, which provides static images, fluoroscopy allows continuous observation of the object in motion, often used for diagnostic and interventional procedures.

Key Features:

1. **Real-time Imaging**: Provides live images on a monitor, allowing for real-time observation of processes such as swallowing, heart movement, or internal part functioning.
2. **X-ray Source**: A continuous X-ray beam is used to create the live images.
3. **Image Intensifier/Detector**: The X-rays pass through the object and are detected by an image intensifier or a digital detector, which converts the X-rays into visible light and digital images that can be displayed on a monitor.
4. **Contrast Media**: In medical applications, a contrast agent (like barium or iodine) is often introduced to enhance the visibility of soft tissues, blood vessels, or the digestive tract.
5. **Applications**:
   - **Medical**: Used in procedures like barium studies, angiography, catheter insertion, joint movements, and surgical guidance.
   - **Industrial**: Used to observe dynamic processes inside machinery or components, particularly during operational tests or real-time defect detection.

(ii) Xeroradiography:

Xeroradiography is an imaging technique that uses X-rays in combination with a xerographic process to produce high-contrast images, commonly used for soft tissue imaging in medical applications and sometimes for industrial inspections.

Key Features:

1. **Xerographic Process**: It relies on the principles of xerography, similar to photocopying. The image is created by exposing a **photoconductive surface** (usually selenium) to X-rays. The surface holds an electrical charge in areas not exposed to X-rays, while the X-ray-exposed regions lose the charge.
2. **Toner Application**: A powder toner is applied to the charged photoconductive surface. The charged areas attract the toner, forming an image.
3. **Image Transfer**: The toner image is then transferred onto a paper or plastic sheet to create a permanent, high-contrast image.

4. **High-Contrast Images**: Xeroradiography produces images with very sharp edge contrast, making it particularly useful for detecting fine details such as skin surface features, soft tissue structures, and certain industrial defects.
5. **Applications**:
   - **Medical**: Historically used for **mammography** and **dentistry** due to its ability to produce high-contrast images of soft tissues.
   - **Industrial**: Used for inspecting fine details in components like electronic circuits or detecting surface defects in materials.

Comparison of Fluoroscopy and Xeroradiography:

Feature	Fluoroscopy	Xeroradiography
Image Type	Real-time, dynamic images (moving).	Static, high-contrast images.
Imaging Principle	Continuous X-ray exposure with image intensification.	Xerographic process with photoconductive materials.
Applications	Primarily used for real-time observation.	Mainly used for high-contrast imaging of soft tissues.
Technology	X-ray beam with image intensifier or digital detector.	X-ray exposure with toner-based image creation.
Radiation Exposure	Higher due to continuous X-ray exposure.	Comparable to traditional X-ray techniques.

Both fluoroscopy and xeroradiography serve different purposes, with fluoroscopy being a dynamic imaging method and xeroradiography offering sharp, static images ideal for specific high-contrast inspections.

5. **Explain the working of radiography testing method. What are the advantages of gamma Radiography compared to X-ray radiography? What are the penetrometers of Radiography testing? List the different types of penetrometers.**

Working of Radiography Testing Method:

Radiography Testing (RT) is a non-destructive testing (NDT) method used to detect internal flaws, defects, or discontinuities in materials. It utilizes **X-rays** or **gamma rays** to penetrate the object and capture images of its internal structure.

Steps in Radiography Testing:

1. **Radiation Source**:
   - **X-ray radiography**: Uses X-rays produced by an X-ray tube.
   - **Gamma radiography**: Uses gamma rays emitted by a radioactive source like Iridium-192 or Cobalt-60.
2. **Object Placement**:
   - The object being tested is placed between the radiation source and a **detector** or **film**. The radiation passes through the object, and varying degrees of absorption occur based on the density and thickness of the material.
3. **Detection/Imaging**:

    - A detector (e.g., radiographic film, digital detector) is placed behind the object to capture the radiation that passes through it. Areas with flaws (like cracks or voids) will absorb less radiation, creating darker areas on the image, while denser, intact areas absorb more radiation and appear lighter.
4. **Image Development**:
    - If traditional film is used, it must be chemically processed to develop the radiograph. In digital systems, the detector captures the image electronically, which can be viewed and analyzed immediately on a computer.
5. **Image Interpretation**:
    - The radiograph or digital image is examined for differences in density and contrast. Defects like cracks, voids, inclusions, and porosities are identified based on variations in the image.

Advantages of Gamma Radiography Compared to X-ray Radiography:

1. **Portability**:
    - **Gamma radiography** is more portable because gamma-ray sources are small and compact, allowing for easier field use in remote or hard-to-reach locations.
    - **X-ray equipment** requires large, heavy machines that are more difficult to transport.
2. **No Need for Power Source**:
    - Gamma radiography does not require electricity to generate radiation, making it suitable for areas without a power supply.
    - X-ray radiography needs a continuous power source to operate the X-ray tube.
3. **Higher Penetrating Power**:
    - Gamma rays, especially from high-energy sources like **Cobalt-60**, can penetrate thicker or denser materials than X-rays, making them suitable for inspecting large structures like pipes, tanks, and heavy components.
4. **Durability of the Source**:
    - Gamma sources are long-lasting, often providing a reliable source of radiation for years, whereas X-ray tubes have a finite life span and require periodic replacement or maintenance.
5. **Cost-Effectiveness**:
    - Gamma radiography is often more cost-effective for field inspections, as it doesn't require expensive power generation equipment or complex machinery.

Penetrometers in Radiography Testing:

Penetrometers, also known as **Image Quality Indicators (IQIs)**, are devices used in radiographic testing to assess the quality of the radiograph. They ensure that the image is of sufficient quality to detect potential flaws and measure the sensitivity of the test.

Functions of Penetrometers:

- Indicate the **quality** and **sensitivity** of the radiograph.
- Ensure the radiographic setup is capable of detecting specified flaw sizes.
- Serve as a calibration reference to verify the proper exposure of the film or detector.

Types of Penetrometers:

1. **Wire-Type Penetrometer**:
    - Consists of a set of thin wires of varying diameters embedded in plastic.

- The radiograph must display the thinnest wire that corresponds to the minimum detectable flaw size.
    - Commonly used for **metallic materials**.
2. **Step/Hole-Type Penetrometer** (ASTM Type):
    - Has a series of steps with varying thicknesses or holes drilled into the plate.
    - The thickness or diameter of the holes correlates with the image quality and sensitivity.
    - Often used for non-metallic materials or complex geometries.
3. **Plaque-Type Penetrometer** (DIN Type):
    - A flat plaque with small holes of varying diameters drilled into it.
    - The visibility of the holes on the radiograph helps determine the sensitivity of the test.
4. **Duplex Wire Penetrometer**:
    - A more advanced type with two wires running side by side.
    - Used for digital radiography (DR) and computed radiography (CR) to check the system's spatial resolution.

6. **Explain the process of Neutron Radiography and Computed Tomography.**

Neutron Radiography (NR) and Computed Tomography (CT) are advanced non-destructive testing (NDT) methods used to inspect internal structures of materials without damaging them. Each uses different radiation sources and processes to create detailed images of an object's internal features.

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1. Neutron Radiography (NR)

Process of Neutron Radiography:

Neutron radiography is an imaging technique that uses neutrons (instead of X-rays or gamma rays) to inspect materials. Neutrons interact differently with materials compared to X-rays, making this method especially useful for detecting low-density materials within high-density objects.

Steps in Neutron Radiography:

1. **Neutron Source**:
    - A neutron source is required, typically a **nuclear reactor**, **radioisotope source**, or a **spallation source**. The neutrons are generated and collimated into a narrow beam.
2. **Object Placement**:
    - The object to be inspected is placed between the neutron source and a **detector** (similar to film or digital detector used in radiography). Neutrons pass through the object.
3. **Neutron Interaction**:

- Neutrons are absorbed or scattered by different elements depending on their atomic structure. Unlike X-rays, which are absorbed more by high-density materials like metals, neutrons are absorbed more effectively by **light elements** such as hydrogen, carbon, and boron.
- This unique interaction makes neutron radiography particularly useful for imaging materials like **plastic**, **rubber**, **water**, and **organic materials** within **metallic enclosures**.

4. **Image Capture**:
   - After passing through the object, the neutrons are detected by a **neutron-sensitive detector**, such as a photographic film coated with a neutron converter, or a digital detector.
   - The variation in neutron absorption creates an image on the detector, revealing the internal structure of the object. Materials with different neutron absorption properties appear with different contrasts on the image.

Applications of Neutron Radiography:

- Inspection of **composite materials** like carbon-fiber components.
- Detection of **corrosion** or **water ingress** in metal structures.
- Inspection of **explosive devices** or **munitions** where neutron radiography can reveal the internal contents without detonating the device.
- Examining **fuel cells**, **aircraft components**, and **turbine blades**.

2. Computed Tomography (CT)

Process of Computed Tomography (CT):

Computed Tomography (CT) is an advanced imaging technique that combines X-rays (or other radiation sources) with computer processing to create cross-sectional (slice-by-slice) images of an object. These images are then combined to produce a detailed 3D model of the object's internal structure.

Steps in CT Imaging:

1. **Radiation Source**:
   - **X-ray CT**: In industrial CT scanning, X-rays are typically used. However, **neutron CT** or **gamma CT** is also possible depending on the materials being inspected.
   - The X-ray source rotates around the object, emitting a beam of X-rays that passes through the object.
2. **Object Rotation**:
   - The object is placed on a rotating platform. The X-rays penetrate the object from different angles as the platform rotates.
3. **Detectors**:
   - A series of **detectors** (either film or digital) are positioned around the object to capture the X-rays that pass through it. The detectors measure the intensity of the X-rays at different angles, creating a series of 2D projection images.
4. **Image Reconstruction**:
   - A computer algorithm processes the collected data to reconstruct cross-sectional images of the object. By combining these 2D slices, a detailed 3D image or **volume model** of the object's internal structure is generated.
5. **Image Visualization**:
   - The reconstructed images can be viewed as slices or a complete 3D model. These images can be manipulated (rotated, zoomed) and analyzed for defects such as cracks, voids, or inclusions within the object.

Applications of Computed Tomography (CT):

- **Medical CT**: Used to visualize human tissues and organs for diagnostic purposes.
- **Industrial CT**:
  - Inspection of **complex internal geometries** in components such as **turbine blades**, **automotive parts**, and **electronic circuits**.

- Detection of internal flaws such as **cracks**, **voids**, and **porosity** in materials.
- Reverse engineering, where a 3D model of a physical object is created to replicate or analyze its structure.
- Inspection of **additive manufactured (3D printed) components** for defects

Comparison of Neutron Radiography and Computed Tomography:

Feature	Neutron Radiography (NR)	Computed Tomography (CT)
Radiation Source	Neutrons (nuclear reactor, spallation source, etc.)	X-rays (or other radiation sources)
Imaging Type	2D projection images	3D cross-sectional and volume images
Material Sensitivity	Sensitive to light elements (hydrogen, carbon, etc.)	Sensitive to density variations, often used for metals
Penetration Capability	Penetrates metals while imaging low-density materials	Best for high-density materials (e.g., metals, ceramics)
Applications	Water content, corrosion in metals, explosives, fuel cells	Aerospace, automotive, electronics, reverse engineering
Output	Single radiographs (2D images)	3D model with slice-by-slice analysis