Rohini College of Engineering and Technology
(Autonomous)

DEPARTMENT OF MECHANICAL ENGINEERING

OML351
INTRODUCTION TO NON-DESTRUCTIVE TESTING

UNIT III EDDY CURRENT TESTING & THERMOGRAPHY

Thermography- Principles, Contact and non-contact inspection methods, Techniques for applying liquid crystals, Advantages and limitation - infrared radiation and infrared detectors, Instrumentations and methods, applications. Eddy Current Testing-Generation of eddy currents, Properties of eddy currents, Eddy current sensing elements, Probes, Instrumentation, Types of arrangement, Applications, advantages, Limitations, Interpretation/Evaluation.

INTRODUCTION

Thermography testing is a non-destructive testing (NDT) imaging technique that allows the visualization of heat patterns on an object.

It is also called as thermal imaging, infrared (IR) thermography or simply thermography.

PRINCIPLE

This testing method is based on the fact that most components in a system show an increase in temperature when malfunctioning or due to variation in temperature difference at the sub surface detects. This temperature differences (DT) observed on the investigated surface during inspection will be monitored by an infrared camera.

The principle, techniques, instrumentation, advantages, limitations and applications of thermography testing are discussed in the following sections.

BASICS OF INFRARED THEORY

Heated object radiates electromagnetic energy. The amount of energy is related to the objects temperature. The energy from a heated object is radiated at different levels across the electromagnetic spectrum.

In most industrial applications it is the energy radiated af infrared wavelengths which is used to determine the object temperature.

The electromagnet spectrum includes X-rays, ultrasonic, infrared (IR) and radio. They are all emitted in the form of a wave and travel at the speed of light. The only difference between them is their wavelengths which are related to frequency.

INFRARED RANGE WITHIN THE ELECTROMAGNETIC SPECTRUM

Infrared radiation is that part of the electromagnetic spectrum that is immediately adjacent to the red light approximate 760 nm on the long wave side of the visible spectrum and extends to a wavelength of approximate 1 mm. This range of wavelength corresponds to frequency at approximately 430 THz down to 300 GHz. range of

In this respect, the wavelength range of upto approximate 20 µm is of importance to identify temperature distribution due to cracks and sub-surface defects.

Characteristics of Infrared

Some of the important characteristics of infrared are as follows:

(i) It is not visible as its wavelength is larger than the visible light.
(ii) It is radiated naturally from all objects having the temperature of absolute 0°K or higher, hence it is applicable to all kinds of field.
(iii) It has characteristics of heating an object, hence it is sometime called as "heat ray".
(iv) It is a kind of electromagnetic wave and it can travel through vacuum.
(v) Infrared energy and temperature of an object are co-related, therefore temperature distribution can be observed.

WAVELENGTH AND FREQUENCY

1. Wavelength

Wave length is the distance between successive crest of a wave, especially in an electromagnetic wave.

2. Frequency

Frequency is the number of occurrences of a repeating event per unit time or simply number of oscillations per second.

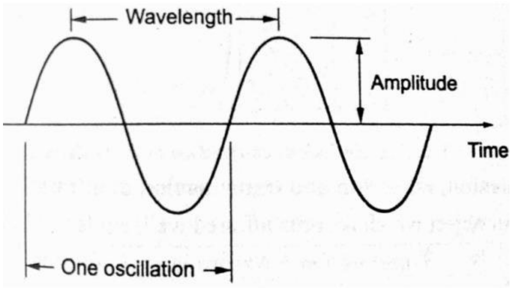


Figure. Frequency

The relationship between wavelength and frequency electromagnetic wave is:

$$\lambda V = C$$

where
λ = Wavelength,
V = Frequency, and
C = Speed of the light

HEAT TRANSFER AND EMISSIONS

1. Emission

A type of heat transfer where the heat is transferred directly from the surface of an object as an infrared energy

2. Convection

A type of heat transfer where the heat is transferred by the heated part of gas or liquid moving upward

3. Conduction

A type of heat transfer mainly through a solid object.

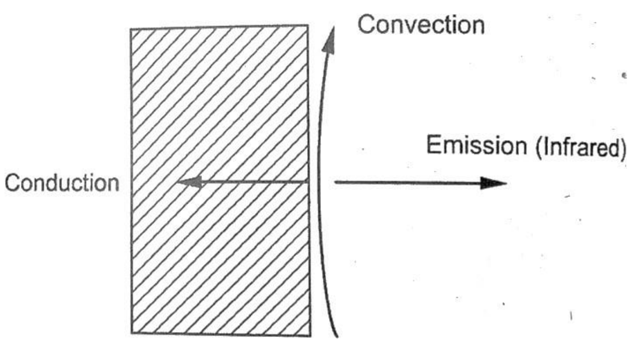


Figure. Emission , Convection and Conduction

4. Emission, reflection and transmission of infrared

An object which absorbs infrared well emits infrared well.

W = Transmission + Absorption + Reflection

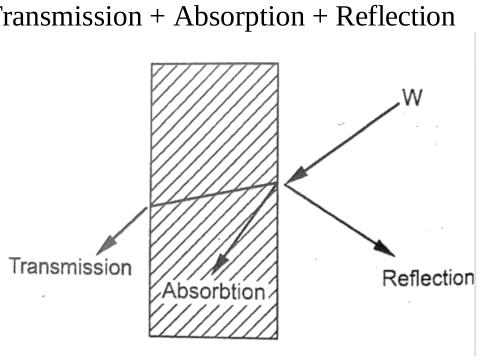


Figure. Emission, reflection and transmission of infrared

If transmission = 0, then
W = Emission + Reflection

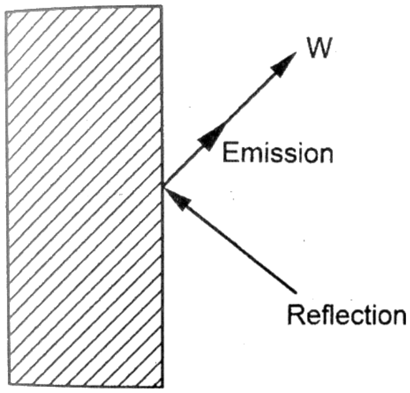


Figure. Emission, reflection

5. Emissivity

- The amount of energy radiated from an object is dependent on its temperature and its emissivity.
- An object which has the ability to radiate the maximum possible energy for its temperature is known as black body.
- In practical applications, there is no perfect emitter and surfaces tend to radiate somewhat less energy a black body. why objects are not perfect emitters of infrared energy. A smaller quantity of energy is reflected back inside and never escapes by radioactive means. Evident that only 70% of the available emitted.

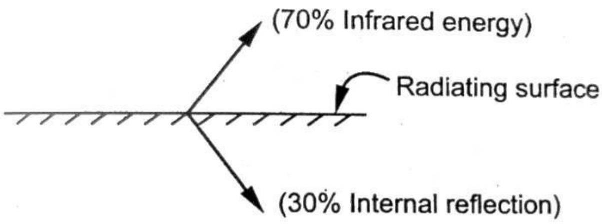


Figure. Emissivity

- Emissivity (e) is defined as the ratio of heat radiated by a re object (Hobiect at a given temperature to the heat that who have been radiated by an ideal black body (Hblack body) at the same temperature.
- Mathematically,

$$€ = H_{object} / H_{black\ body}$$

- Thus € 1 signifies that the body is a perfect black body, materials like lamp black, are having € 0.95 and a considered to be a black body for all practical purposes.
- One common way of converting a non-black body to a black body is to apply a thin layer of black paint on it. The thin layer paint, being in contact with the body, will have the same temperature as that of the body. So overall the object will act like a black body.

6. Effects of Emissivity

If a material of high emissivity and one of low emissivity were placed side by side in the furnace and heated to exactly the same temperature the material with low emissivity would appear to the eye much duller. This is due to the different emissivity of the materials causing them to radiate at different levels.

BASIC PRINCIPLE OF THERMOGRAPHY TESTING

Principle

- The principle of infrared thermography testing is based on the physical phenomenon that any body of a temperature above absolute zero (-273.15°C) emits electromagnetic radiation. There is a clear correlation between the surface of a body and the intensity and spectral composition of its emitted radiation
- By determining its radiation intensity the temperature of an object can be determined in a non-contact way.

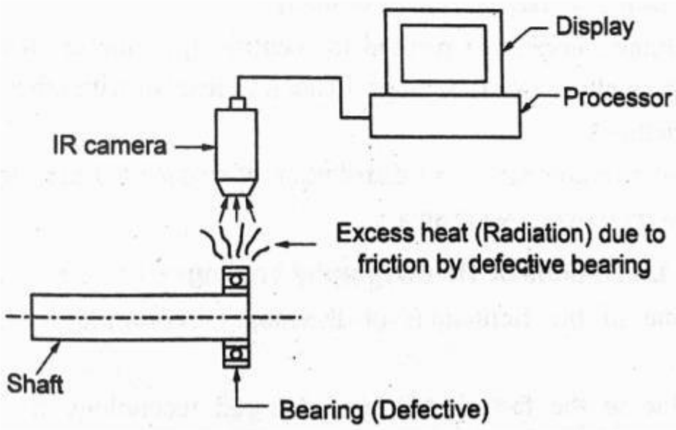


Figure. Principle of Thermography Testing

- Thermography testing uses an infrared camera containing large number of infrared sensors which can detect and measure small temperature differences. The image showing the temperature differences can be processed and displayed as a colour or grey scale map.

ADVANTAGES OF THERMOGRAPHY TESTING

Some of the advantages of thermography testing are as follows:

(i) This technique is highly effective and very easy to use.
(ii) Compared to many other inspection techniques, it is fast and it can create a thermal image.
(iii) Large areas can be scanned fast, hence major savings in time, people, work and machinery.
(iv) Thermographic device is risk free as it does not emit any radiation.
(v) Thermographic testing may be performed during both day and night time hours.
(vi) Thermographic testing is a technique (No couplant is needed as in the case of ultrasonic testing)
(vii) Results are relatively easy to interpret.
(vii) Unique inspection method to identify open micro cracks in thermally sprayed coatings difficult to inspect with other NDT methods.
(ix) Relative comparison of distribution of surface temperature can be used over a wide area.

LIMITATIONS OF THERMOGRAPHY TESTING

Some of the limitations of thermography testing are given below.

(i) Due to the fact that it uses infrared technology it is not possible to penetrate in extended depths (only few millimeters).
(ii) Thermal losses by convection and radiation that might induce spurious contrasts affecting the reliability of the interpretation.
(iii) Surface painting is required in low emissivity materials toincrease and equalize emissions.
(iv) Active thermography equipment is more expensive than ultrasound devices.
(v) Capability to detect only defects resulting in a measurable change of the thermal properties from the inspected surface.
(vi) Reflective surfaces that cannot be made more emissive, the subsurface condition may not be resolved.

CLASSIFICATION OF THERMOGRAPHY TESTING

Thermography testing can be broadly classified as follows:

(a) On the basis of approaches
- (i) Passive
- (ii) Active

(b) On the basis of configuration
- (i) Static
- (ii) Dynamic

(c) On the basis of modes
- (i) Transmission
- (ii) Reflection
- (iii) Internal

(d) On the basis of scanning
- (i) Point
- (ii) Line
- (iii) Surface

(e) On the basis of sources
(i) Optical
(ii)Mechanical
(iii) Inductive

(f) On the basis of waveforms
(i) Modulated
(ii) Pulse
(iii) Square pulse
(iv) Step

THERMOGRAPHY TESTING - ACTIVE APPROACH

In active thermography approach, an external stimulus is needed to produce a thermal contrast in the object surface. When external source of heat is applied the thermal state of the object to be inspected is destabilized.

Internal defects in the object like voids, cracks, delaminating, foreign material inclusion etc causes thermal disequilibrium and resulted in distinctive surface thermal patterns between the defects and sound material.

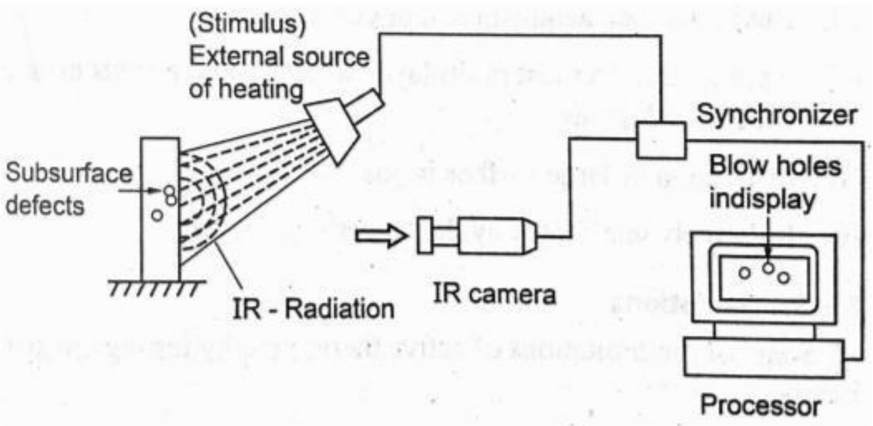


Figure. Thermography Testing - Active Approach

The active approach of thermography testing. In this technique, the sample is heated by an external source (optical, mechanical, electromagnetic or other). Controlled heat source and its surface temperature is monitored as a function of time through changes of emitted infrared radiation.

The specific thermal properties of material under test influence transport of heat thus causing surface temperature to change with respect to areas with different thermal properties. Due to the thermo physical properties of the testing material defective and non-defective surface produces a measurable thermal constant.

IR camera acquires data on thermal emissions and is displayed in the computer. The appearance of subsurface defect is proportional to its depth. The time of application of the external heat source can be synchronized with the acquisition system; quantitative data analysis is possible by this method.

ADVANTAGES

Some of the advantages of active thermography testing are as follows.
(i) Possibility to perform one-sided inspection.
(ii) Real time data acquisition is possible.
(iii) Appropriate on most multi-layer structure and porous material used in industries.
(iv) Inspection of large surface is possible.
(v) Relatively unaffected by the object's geometry.

LIMITATIONS

Some of the limitations of active thermography testing are given below.
(i) Sensible to duration of heating source.
(ii) Expensive (as the Response time is very fast in case of metals hence faster data acquisition system is required).

APPLICATIONS

The typical applications of active thermography include:
(i) Structural evaluation of Glass Reinforced polymer (GRP pipes.
(ii) Assessment of damage on Carbon Fiber Reinforced Plast(CFRP) panels.
(iii) Checking sand witched panels of aircrafts.
(iv) Identification of sub-surface defects like cracks, blowhole porosity and inclusions in metals.

ACTIVE THERMOGRAPHY TECHNIQUES
(Types of Active Thermography Testing)

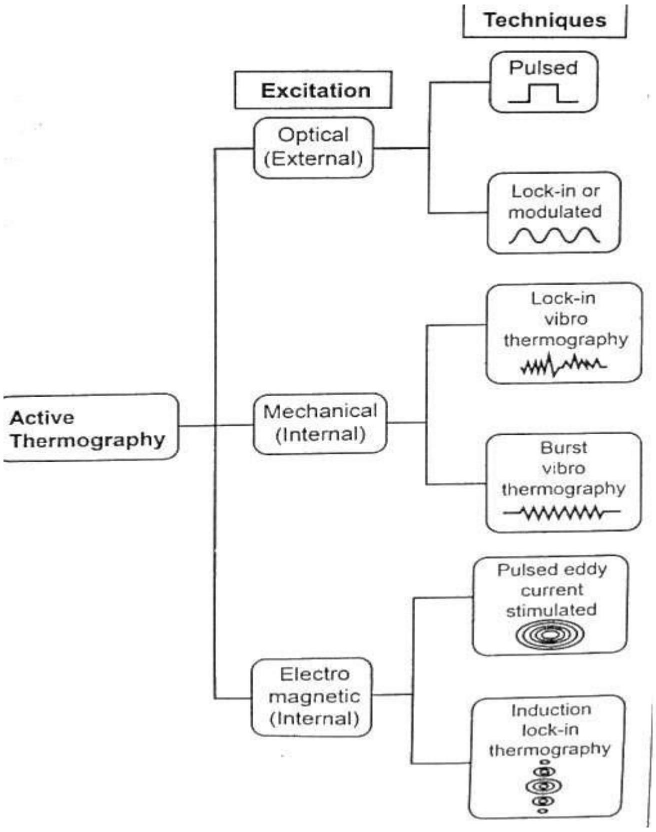


Figure. Active Thermography PULSED

THERMOGRAPHY (FLASH THERMOGRAPHY)

Concept

In this technique, energy sources (xenon flash tubes) are used to pulse-heat the specimen surface. The duration of the pulse may vary from a few microseconds by using flashes to several seconds by using lamps.

The duration and energy source depends on the thermo physical properties of both, the specimen and the flaw. Depicts the principle of pulsed thermography.

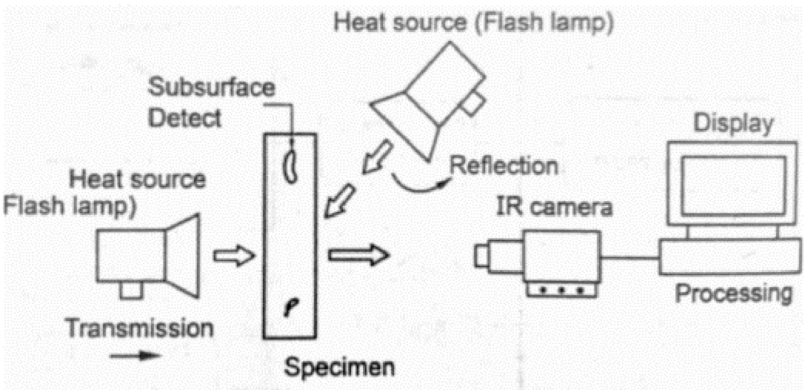


Figure. Pulsed Thermography

Modes of thermography: The specimen is heated from one side while thermal data is collected either from the same side (reflection mode) or from the opposite (transmission mode).

(i) **Reflection mode:** In this mode, inspecting defects closer to the heated surface.
(a) Depicts the principle of reflection mode pulsed thermography.

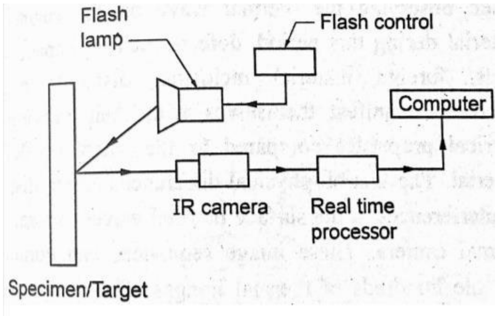


Figure. Block diagram of pulsed (reflection mode) thermography

(ii) **Transmission mode:** In this mode, inspecting defects closer to the non-heated surface (Deeper defects). depicts the principle of transmission mode pulsed thermography.

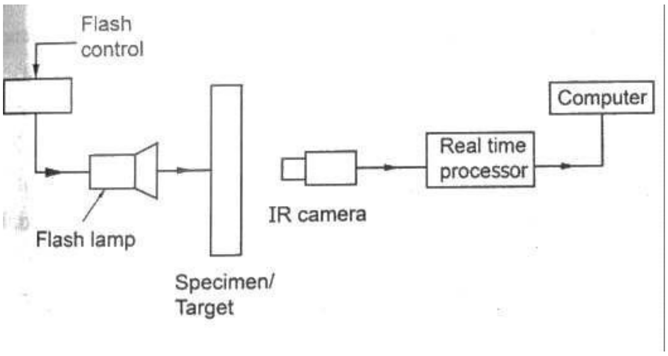


Figure. Block diagram of pulsed (Transmission mode) thermography

Detective zones will appear at higher or lower temperature with respect to non-defective zones on the surface, depending on the thermal properties of both the material and the defect. The temperature evolution on the surface is then monitored using an infrared camera.

When observing the thermal wave on the surface of the material during this period, defects such as impact damages, voids, foreign material inclusion, disbands and water inclusions manifest themselves with their varying thermo physical properties compared to the intact or defect free material. The thermo-physical differences create disturbances or interferences in the surface thermal waves, are recorded by thermal camera. These image sequences can contain up to multiple hundreds of thermal images. The analysis software then calculates a result image that based on the applied algorithm.

THERMOGRAPHIC SIGNAL RECONSTRUCTION

- Pulsed (flash) thermography is most readily applicable to situations where the diameter of a subsurface defect is greater than its depth beneath the surface. As the defects aspect ratio approaches unity or less, the maximum temperature difference between a defect and the surrounding intact areas decreases, P often to level comparable to the noise level of the IR camera, and is not detectable in the raw camera data. For these low d aspect ratio applications, or for quantitative measurement of physical properties, additional signal processing is required. In these cases, the Thermographic Signal Reconstruction (TSR) method provides a significant degree of improvement in terms the of sensitivity, reduction of blurring and depth range compared to contrast analysis.
- In the thermographic signal reconstruction (TSR) process, several hundred frames of raw data representing the time - history of each pixel are reduced to a set of equations.

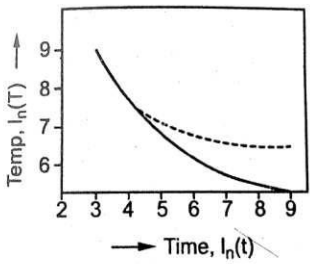


Figure. The difference between raw data and thermography reconstructed signals

- The conversion process typically requires a few seconds. The fact that the TSR information is presented mathematically in a closed form allows advanced manipulation, such as differentiation, calculation of inflection points or Fast Fourier Transforms (FFT) to be performed quickly, and without adverse noise effects.

DATA PROCESSING AND ANALYZING TECHNIQUES OF PULSED THERMOGRAPHY

In pulsed thermography (PT), the specimen surface is submitted to a heat pulse using excitation source such as photographic flashes. Heat pulse produced by flash lamp is a periodic wave with different frequencies and amplitudes. After the thermal front came into contact with the specimen's surface, it travels from the surface through the specimen.

As time elapses, the surface temperature will decrease uniformly for a piece without internal flaws. On the other side. surface discontinuities (e.g., porosity cracks, inclusions, disband etc.,) can be acted as resistances to heat flow that produce abnormal temperature patterns at the surface, which can be detected by IR camera. The distribution of heat in a given region over time can be expressed by the heat equation as follows.

Effusivity (Heat penetration co-efficient (kpc)^{1}2). Thermal changes in the surface of the specimen is recorded by IR camera with the help of synchronization unit to control the time between the launch of the thermal pulse and recording of

Data is stored as a 3D matrix and temperature profile for defective and non-defective areas as shown in the Figure.

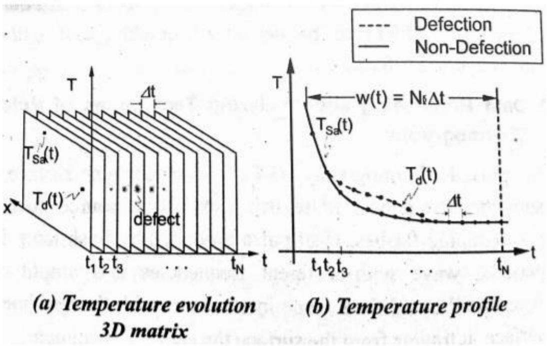


Figure. Data Processing and Analyzing Techniques

ADVANTAGES OF PULSED THERMOGRAPHY

(i) Pulsed thermography is a faster technique and easy to deploy.
(ii) Numerous processing techniques are available.
(iii) Highly suitable to detect voids and inclusions.
(iv) Quantitative assessment of detect is possible.

LIMITATIONS OF PULSED THERMOGRAPHY

(i) Affected by non-uniform heating, emissivity variations, environmental reflections and surface geometry.
(ii) Surface preparation is required for low emissivity materials.
(iii) Thermal losses by convection and radiation may affect the interpretation of result/output.

APPLICATIONS OF PULSED THERMOGRAPHY

(i) Locating anchoring points (through skin sensing) beneath the outer skin of aircraft to facilitate drilling and fixing.
(ii) Defect detection under multiply composite.
(iii) Determination of impact damages on CFRP panels.
(iv) Measurement of drilling induced defects on laminates.
(v) Identification of the cracks in turbine components.
(vi) Detection of water accumulation, corrosion in aircraft passes.

VIBRO THERMOGRAPHY TESTING

Vibro thermography (VT), also known as ultrasound thermography or thermosonics, utilizes the mechanical waves to directly simulate internal defects and without heating the surface as in optical methods (pulsed thermography or lock in thermography).

Principle

In vibro thermography, ultrasonic waves will travel freely through a homogeneous material, whereas internal defect will produce a complex combination of absorption, scattering, beam spreading and dispersion of waves, whose principal manifestation will be in the form of heat. Heat then will travel by conduction in all directions; an IR camera is used to capture the defects in the specimen.

Defect detection is independent from its orientation inside the specimen; both internal and open surface defects can be detected.

There are basically two configurations for vibro thermography. They are:

1. Brust vibro thermography (similar to pulsed thermography), and
2. Lock-in vibro thermography (similar to optical lock-in thermography)

Burst Vibro Thermography

In burst vibro thermography, a burst of ultrasonic waves are injected into the test specimen for a short time and it varies from milliseconds to few seconds.

In this method of testing, the ultra sound wave is produced by a transducer made of a stack of piezo elements and concentrated in a titanium horn that acts like a hammer. Hence, the part being inspected should be firmly immobilized (without damaging the specimen) to avoid cantilever effects, clapping and sliding of the transducer.

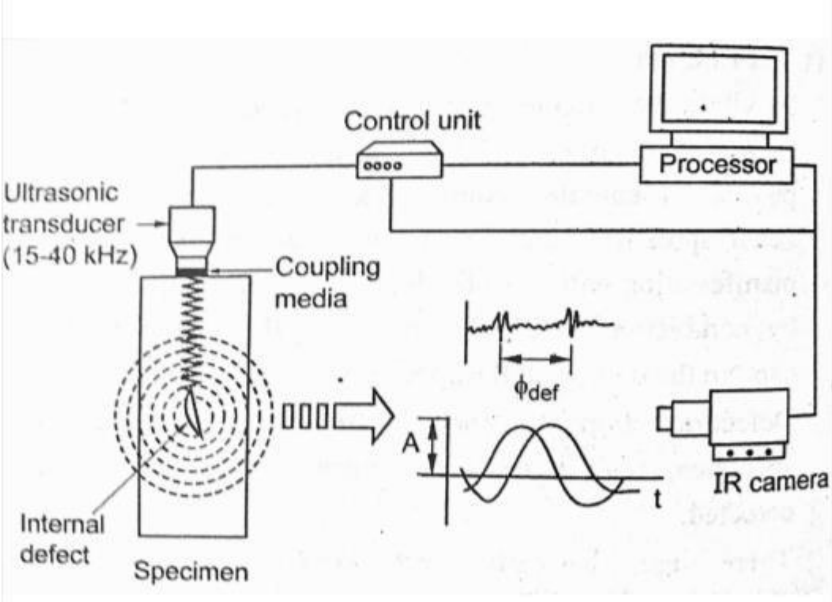


Figure. Burst Vibro Thermography

Insertion of a coupling material like a piece of fabric, water based gel or aluminium between the transducer and the specimen will reduce losses. A bad coupling implies a poor ultrasound transmission, but more seriously it creates unwanted heat in the vicinity of the ultrasound injection point after the mechanical sound waves (ultrasonics) are injected to the specimen, they travel through the material and dissipate their energy mostly at the defects so heat is locally released. The thermal waves then travel by conduction to the surface, where they can be detected with an IR camera. Then the data is processed and displayed in the computer, defects are identified.

Lock in Vibro thermography

Lock-in vibro thermography, also called as amplitude modulated Vibro Thermography, is similar to optical lock in thermography with a difference in excitation source. In this technique mechanical elastic wave at higher frequency is injected to the specimen.

This equipment consists of ultrasonic vibration source, IR camera, control unit, computer with processing software and display unit.

Sonic waves propagate in the material and when they find internal defect they trigger the dissipation of vibration energy into heat mainly by friction between the contacting surfaces of the defect. Subsequently heat is conducted to the surface where it can detected by IR camera.

The frequency and shape of the response curves are preserved; the change is amplitude and phase delay is processed and recorded for analysis.

APPLICATIONS OF THERMOGRAPHY TESTING

Thermography testing is an effective tool for inspection of motors, rotating equipment, steam traps, refractory (passive approach) welded joints and surface cracks (active approach).

Most of the applications are qualitative in nature, often comparing the current thermal image to a previous one and understanding the cause and extend of any changes.

Mechanical Applications

In mechanical parts having relative motions (rotary or sliding) excessive friction produces heat. This may be due to insufficient or over lubrication. Increased surface temperatures can be the result of internal faults like bearings wear, misalignment or inadequate lubrication. In the above circumstances, thermographic testing is conducted to record the current thermal image to previous one and to understanding the extent of any changes. Abnormal heating of a misaligned coupling usually precedes a measurable vibration pattern. This change in vibration signature left unresolved leads to compound problems of other parts like bearing and impellers.

In automotive industry, mass production requires short cycle times and automated processes. In this environment, ultrasound exited thermography (UET) is used as a simulation source for crack detection in automotive components like cylinder block, cylinder head and other parts made by pressure casting process.

EDDY CURRENT TESTING (ECT)

INTRODUCTION

Eddy current testing (ECT) is one of the electromagnetic non-destructive methods.

Principle:

The ECT works on the basis of electromagnetic induction. Eddy currents are induced in a test object using alternative electromagnetic field. Flaw in the tested object causes changes in the eddy current and flow pattern is observed. This change in the current field is useful to identify the defect.

ECT is usually used for the detection of surface and sub surface defects in conducting materials.

This method is complementary to ultrasonic testing for detecting defects close to the surface.

It is also complementary to the liquid penetrant inspection, which cannot reveal sub-surface defects.

The limitation of ECT method is that it cannot be used on non-conducting materials.

The principle, techniques, instrumentation, advantages, limitations and applications of eddy current testing are presented in the following sections.

BASICS OF EDDY CURRENT TESTING

Terminologies Used in Eddy Current Testing presents the summary of various terminologies used in the study of eddy current testing.

Terms used in eddy current testing

1. Electricity: Movement of electrons in a particular direction through a conductor is called as electricity.

2. Conductivity: Conductivity is the relative ability ofmaterial's atom to conduct electricity.

3. Resistivity: Resistivity is the opposition of a material's atoms to the flow of electricity; it is the inverse of conductivity.

4. Conductance: It is the ability of particular componentto conduct electricity.

5. Permeability: Permeability defines a material's ability to be magnetized. Permeability has a dominant effect on eddycurrents.

6. Ampere: It is the measure of flow of current.

7. Volt: It is the measure of electromotive force and is defined as electrostatic difference between two nodes,

8. Ohm's law: It is the basic law of electricity and it relates 8. Fundamental electrical quantity voltage and current.

$$V = I * R$$

where

V = Voltage (volts),

I = Electrical Current (ampere),

R= Resistance (ohms).

9. Current density: It is the current per unit area of the specimen.

10. Induction: It is the process of establishing an electric current in a conductor by placing it in a zone of changing magnetic field. This process is also called as electromagnetic induction.

11. Electromotive force: It is a force, which directs the electrons to move in a prescribed format in certain direction within a conductive material.

12. Electrical impedance: It is the total opposition offered by conductor to alternating current.

13. Inductance: It is the effect produced on flowing current by induction in an electrical circuit.

14. Lenz's law:

Lenz's law states that an induced current has a direction such that its magnetic field opposes the changing magnetic field that induced the current.

This means that the current induced in a conductor will oppose the change in current that is causing the flux to change.

Lenz's law is important in understanding the inductive reactance, which is one properties is measured in eddy current testing.

What are Eddy Currents?

Whenever relative motion occurs between a metal conductor and magnetic lines of force (the motion is produced by movement of the metal conductor or movement of the magnetic lines), electric currents are induced in the surface of the metal conductor. These induced electric currents are commonly referred to as "eddy currents"

Properties of Eddy Currents

Some of the main properties of eddy current are as follows:

(1) Eddy currents are closed loops of induced current circulating in planes perpendicular to the magnetic flux.

(i) They normally travel parallel to the coil's winding and the flow is limited to the area of the inducing magnetic field and perpendicular to the axis of the coil's flux field.
(ii) Eddy current density decreases exponentially with depth. This phenomenon is known as the skin effect.

Generation of Eddy Currents

A probe is used to generate eddy currents for an inspection. Inside the probe is the length of electrical conductor which is formed into a coil. Alternating current is allowed to flow in the coil at a frequency according to the type of test involved.

A dynamic expanding coil collapsing magnetic field forms in and around the coil as the alternating current flows through the coil. When an electrically conductive material is placed on the coil's dynamic magnetic field, electromagnetic induction will occur and eddy currents will be induced in the material.

Eddy currents flowing in the material will generate their own "secondary" magnetic field which opposes the coil's "primary" magnetic field.

This entire electromagnetic induction process to produce Eddy currents may occur from several hundred to several million times per second depending upon inspection frequency.

Fig shows the generation of eddy currents for different types of coil (probe) arrangement.

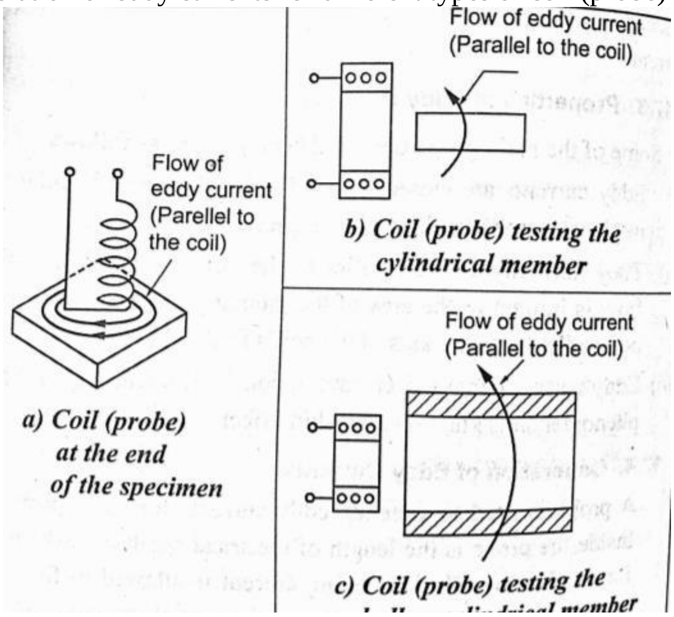


Figure. Generation of Eddy Currents

WORKING PRINCIPLE OF EDDY CURRENT TESTING

Basic Principle

Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field develops in and around the conductor.

This magnetic field expands as the alternating current rises to the maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close to this changing magnetic field, current will be induced in this second conductor. Eddy currents are induced proximity electrical currents that flow in a circular path. They set their name from "eddies" that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right.

When a flaw is introduced in the conductive material to be tested, the eddy currents are disrupted and is sensed through suitable instrumentation.

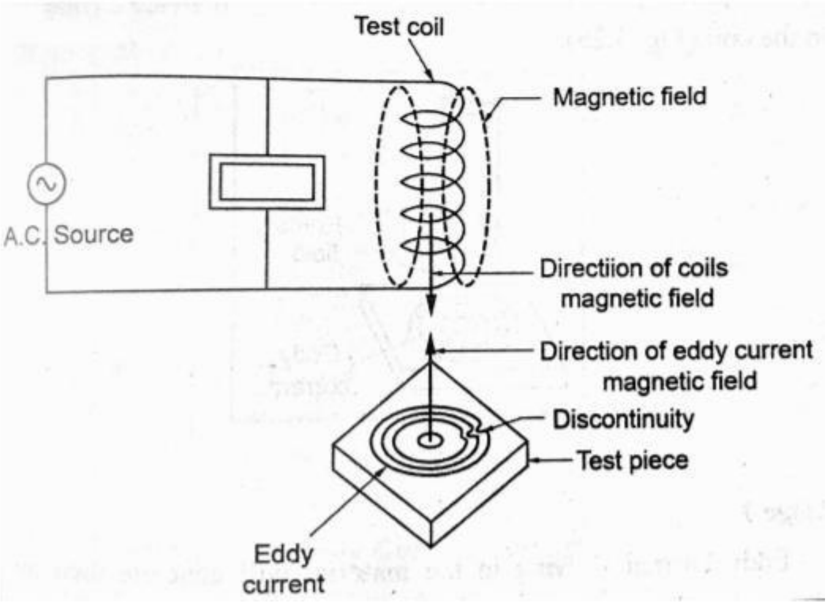


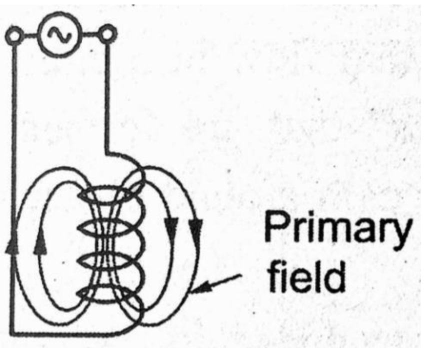
Figure. Basic eddy current testing system

Eddy current testing can detect very small cracks of any Figure. Basic eddy current testing system physical complex geometry with minimal surface preparation.

Eddy Current Test Sequence

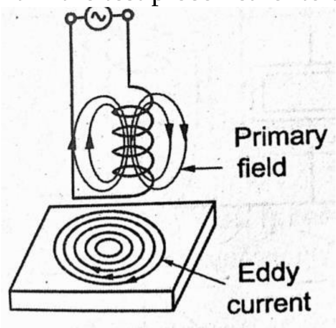
Stage 1

A dynamic expanding and collapsing magnetic field (known as primary field) forms in and around the coil.



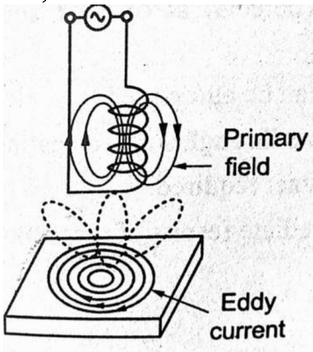
Stage 2

The primary field induces eddy current in the test piece nearer to the coil.



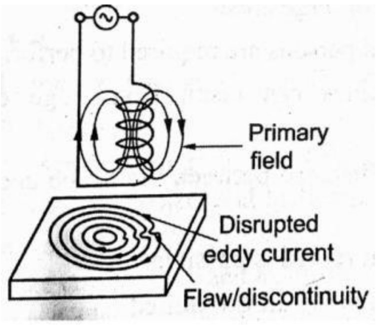
Stage 3

Eddy current flowing in the material will generate their own "secondary" magnetic field which will oppose the coil's "primary magnetic field, which has an effect to the coil impedance.



Stage 4

When a discontinuity is introduced to the conductive test piece, the eddy currents are disrupted and are read by suitable instrumentation.



ADVANTAGES OF EDDY CURRENT TESTING

Some of the main advantages of eddy current testing are below.

1. High speed testing.
2. Accurate measuring of conductivity.
3. Discontinuities (defects) at or near surface can be r detected.
4. This technique can be automated.
5. It can detect flaws through surface coatings.
6. No physical contact required.
7. It provides immediate results of inspection.
8. Low cost.
9. Portable.
10. Complex shape can be inspected.

LIMITATIONS OF EDDY CURRENT TESTING

Some of the limitations of eddy current testing are given below.

1. Limited penetration into test piece.
2. Only suitable for testing conductive materials.
3. Discontinuities are qualitative not quantitative indications.
4. Not suitable for large areas.
5. Highly skilled persons are required to perform inspection.
6. False indications can result from edge effects and parts geometry.
7. Maintaining distance between the probe and test specimen is essential.
8. No permanent record is possible.
9. Interpretation of signal is required.

EDDY CURRENT TESTING INSTRUMENTATION

The basic instruments involved in eddy current testing. Any eddy current test system consists of the following instruments:

(i) An oscillator,
(ii) Test coil,
(iii) Signal processing and filtering,
(iv) Display.

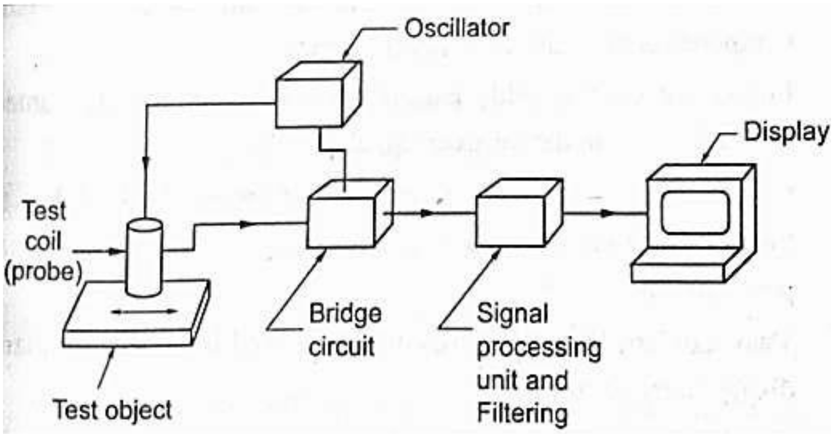


Figure. Eddy Current Testing Instrumentation

1. **Oscillator**

The oscillator provides an alternating current of the required frequency to the test.

2. Test Coil (Probe)

The test coil serves as the main link between the test instrument and the test subject. Object and feeds the information to the signal analysis system.

It establishes a varying electromagnetic field, which induces eddy current in the test object and increases the magnetic effect the in magnetic materials.

It also senses the current flow and magnetic effect within the test. Basic types of coils are:

(i) Encircling coil,
(ii) Coil inside the test object, and
(iii) Surface coil.

3. Single Processing And Filtering

Lift-off and the structures attached with test object. This results in unreliable detection and inaccurate characterization of defects. Hence, signal processing is one of the most important components of a data acquisition system.

Filters are used in eddy current testing to eliminate unwanted frequencies from the receiver signal.

Correct filter settings can significantly improve the visibility of the defect signal, whereas incorrect settings can distort the signal presentation.

Two standard filters that are commonly used in impedance plane display instruments are:

(a) High pass filter (HPF), and
(b) Low pass filter (LPF).

The main function of the low pass filter (LPF) is to remove high frequency interference noise. This noise can come from a variety of sources including the instrumentation and/ or the probe itself.

The high pass filter (HPF) is used to eliminate low frequencies which are produced by slow changes, such as conductivity shift with in material or out of round holes in fastener hole inspection.

4. Displays

Displays can range from single LED and meter readouts to multi-frequency presentations on display screens.

(i) Dedicated display instrument

Dedicated instruments are designed for a specific application and are usually able to perform that application efficiently.

Examples of dedicated instruments are crack detectors, coating thickness gauges, and conductivity meters. These type of instruments, do not provide the quantity of information, and can mislead the unskilled operators.

Impedance plane display instrument

In impedance plane display instrument, each type of material condition deflects the display dot in a characteristic manner, facilitating separation of variables and interpretation of signals.

Impedance plane display instruments show variation of both inductive reactance and resistance during testing.

FACTORS INFLUENCING EDDY CURRENT

(Parameters of Eddy Current Testing)

A number of factors, apart from flaws, will affect the eddy current response from a probe. Successful assessment of flaws or any of these factors relies on holding the others constant, or eliminating their effects on the results. Factors influencing eddy current testing are as follows:

1. Material conductivity,
2. Permeability,
3. Frequency,
4. Design/geometry of the coil,
5. Proximity/lift off, and
6. Skin effect/depth of penetration.

1. Material Conductivity.

The conductivity of a material has a very direct effect on the eddy current flow. The greater the conductivity of a material the greater the flow of eddy currents on the surface. Conductivity if often measured by an eddy current technique and inferences can then be drawn about the different factors affecting conductivity, such as material composition, heat treatment, work hardening etc.

2. Magnetic Permeability

This variable applies only to ferromagnetic materials. Permeability may be defined as the ease with which can be magnetized.

As material permeability increases, noise signals resulting from permeability variations increasingly mask eddy current signal variations. This effect becomes more pronounced with increased depth.

Permeability thus limits effective penetration of eddy currents, Magnetic permeability of various materials which affect the eddy current testing is given below. Para magnetic materials, such as aluminium has a relative magnetic permeability slightly greater than one ($\mu \geq 1$).

Diamagnetic materials like copper and lead create a magnetic field in opposition to an externally applied magnetic field, thus causing repulsive effect. Magnetic permeability is less than one ($\mu r \leq 1$).

Ferromagnetic materials such as iron, nickel, cobalt and their alloys are strongly attracted by magnetic fields and concentrate the flux of magnetic fields. Their relative permeability is much greater than are (ur>> 1). One hundred to several hundred are typical values of relative permeability.

3. Frequency

Eddy current response is greatly affected by the test frequency selected. ✓ Eddy current testing is performed within a frequency range of approximate 50 Hz to 10 MHz.

- As test frequency is increased, sensitivity to surface discontinuities increases, permitting increasingly smaller surface discontinuities to be detected.
- As frequency decreased, eddy current penetration into the material increases.
- In addition, as frequency is decreased, the speed of coil motion must be decreased in order to obtain full coverage. The optimum frequency is best determined by experimentation.

4 Design/Geometry of Coil

- In real testing, geometrical features such as curvature, edges, grooves etc., will exist with the part to be tested and will affect the eddy current response.
- Sensitivity to small surface discontinuities requires that the eddy current field be sufficiently compact so that it will be adequately distorted by the discontinuity. Also penetration requires that the eddy current field extend to the required depth of specimen.
- The thumb rule is that eddy current penetration limited to a depth equivalent to the coil diameter.

5. Proximity/Lift off

- The distance between a surface coil and the test surface is called as proximity or lift off.
- Since flux density decreases exponentially with distance from the test coil, the amount of lift off or separation between the coil and test specimen has a significant impact on sensitivity.
- The closer the coupling between coil and test specimen, the denser the eddy current field that can be developed, and thus the more sensitive the test to any material variable.

6. Skin Effect/Depth of Penetration

- Eddy current concentrate near to the surface adjacent to on excitation coil and their strength decreases with distance from the coil. Eddy current density decreases exponentially with depth. This phenomenon is known as the skin effect.
- Skin effect arise when the eddy currents flowing in the test object at any depth produce magnetic fields which opposes the primary field, thus reducing the net magnetic flux and causing a decrease in current flow as the depth increases,
- Alternatively, eddy currents near the surface can be viewed as shielding the coil's magnetic field, there by weakening the magnetic field at greater depths and reducing induced currents. It is mathematically convenient to define the "Standard depth of penetration" where the eddy current is 37% of its surface value,

EDDY CURRENT TESTING PROBES

Eddy Current Testing Probes on the Basis of Mode of Operation

- Eddy current probes are classified on the basis of modes of operation i.e., the way by which eddy current instruments interfaces with the test specimen. Four general categories are:
  1. Absolute probes,
  2. Differential probes,
  3. Reflection and probes and
  4. Hybrid probes.

1. Absolute Probes

Absolute probe, also called as single coil probe, in which any change in material geometry (defects) can be detected by excitation coil as a change in coil impedance. Absolute probes can be used for flaw detection, conductivity measurement, and thickness measurements.

The simplest coil comprises a ferrite rod with several turns of wire wound at one end and which is positioned close to the surface of the product tested. When a crack, for example, occurs in the product surface the eddy currents must travel farther around the crack and this is detected by the impedance change.

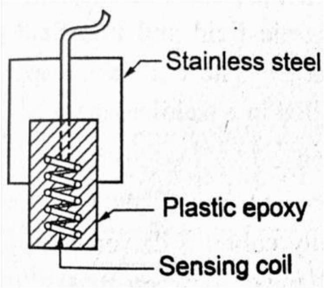
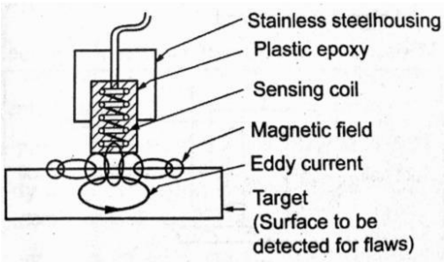


Figure. Arrangement of sensing element of the eddy current testing

- Below figure shows the eddy current sensor generating eddy current in operation.



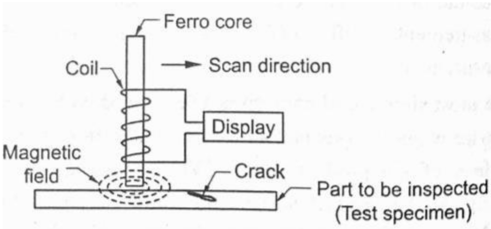


Figure. Eddy current sensor generating eddy current in operation

Primary functional element of the eddy current probe is the sensing coil. This is a coil of wire near the end of the probe. Alternating current is passed through the coil which creates an alternating magnetic field and this field is used to sense the defect in the target. The coil is encapsulated in plastic and epoxy and installed in stainless steel housing.

2. Differential Probes

- Differential probe consists of two active coils and are arranged in pairs, generally called a driven pair, and this arrangement can be used with the coils connected differentially.
- When a flawless test specimen is tested using this probe, no differential signal is developed between these two active coils. However when one coil is over flawed part of a test specimen and the other one is over flawless part of the same specimen, a differential signal is produced.

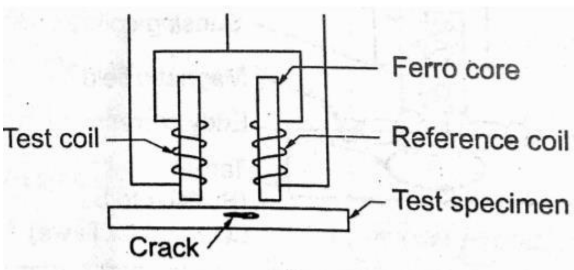


Figure. Differential Probes

3. Reflection Probes

- Reflection probes combine the features of both absolute and differential probe. Here one coil is used to generate eddy current and other one is coupled to a reference standard, which evaluates the change in test specimen whenever indications from test specimen differs from the standard.
- This type of probe is with 3 windings i.e., primary and two secondary windings, hence it is also called as probe with transformer type coil.

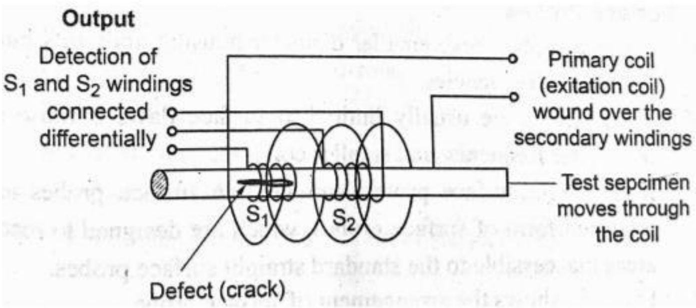


Figure. Reflection Probes

4. Hybrid Probes

- Hybrid probe consists of a driver coil working on reflection mode and surrounded by two sensing coil working on differential mode. These probes are very sensitive to surface defects only.

Eddy Current Testing Probes on the Basis of Applications

Different types of eddy current probes are used for various applications. That are:

1. Surface probes, 2. Rotating scanner probes, 3. Manual bolt hole probes, 4. Bobbin probes, 5. Spot probes, 6. Weld probes, 7. Sliding probes, 8. Doughnut probes, 9. Encircling probes, and 10. Pencil probes

1. Surface Probes

Surface probes have smaller diameter housing and coils built for higher frequencies. Applications are usually limited to surface flaws because of the higher frequency and smaller coil size.

Right angle surface probes and flexible surface probes are modified form of surface probes, which are designed to reach areas inaccessible to the standard straight surface probes.

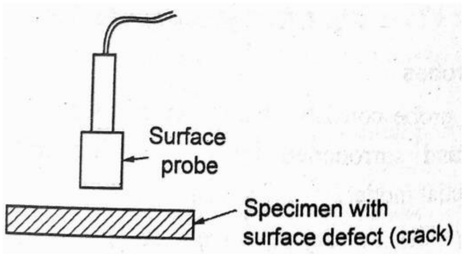


Figure. Surface Probes

2. Rotating Scanner Probes

Rotating scanner probes are used with mechanical devices for automatically rotating the probe in the hole.

These types of probes are provided with differential coils and maintain close tolerance yielding reliable results. Fig shows the arrangement of rotating scanner probe.

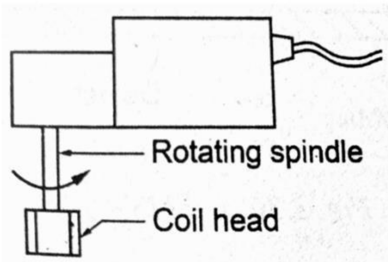


Figure. Rotating Scanner Probes

3. Manual Bolt hole Probes

Manual bolt hole probes have coils located at right angles to the probe direction, and are rotated by hand with the fastener removed.

Standard and custom size diameters are available with absolute and differential coils.

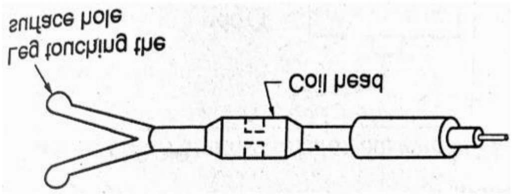


Figure. Manual Bolt hole Probes

4. Bobbin Probes

Internal bobbin probes are meant for hallow circular sections especially used in inspection of heat exchanger tubes.

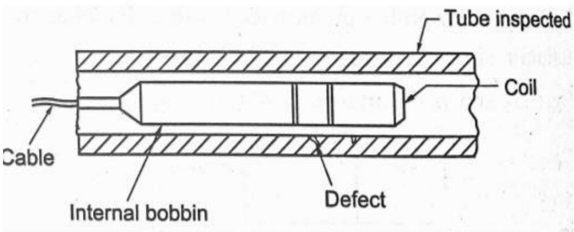


Figure. Bobbin Probes

5. Spot Probes

Spot probes are used for both surface and subsurface. The diameter of the probes is usually large for accommodation lower frequencies or scanning larger areas. Because of the larger diameter coil the detectable flaw size also increases.

6. Weld Probes

Weld probes are designed to inspect ferrous welds. They provide a cost-effective alternative to magnetic particle inspection, which requires the part to be cleaned prior t inspection.

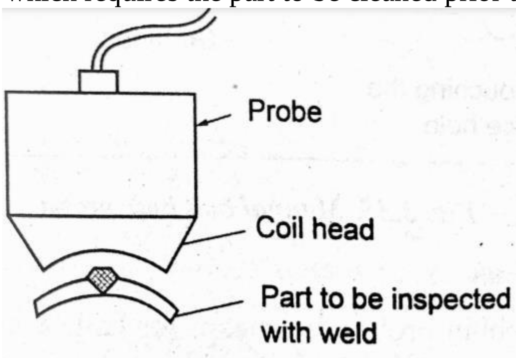


Figure. Weld Probes

7. Sliding Probes

Sliding probes are designed to inspect aircraft fastener holes with fastener in place, at higher scan rates than spot probes.

Standard sizes and frequencies using the reflection coil techniques are often applied in major air frame inspection requirements.

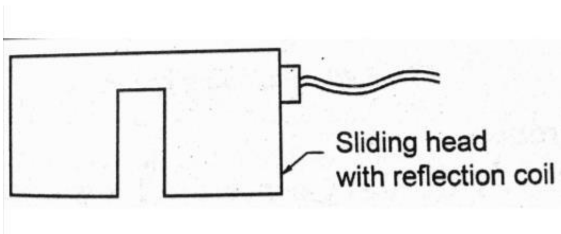


Figure. Sliding Probes

8. Doughnut Probes

Doughnut probes are designed to fit above the rivet or bolt hole and inspect for any defect.

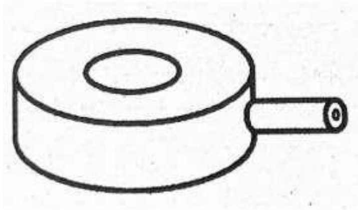


Figure. Doughnut Probes

9. Encircling Probes

In this type of probes, the coil encircles the test specimen from outside and are used for testing of rods, wires, pipes, tubes etc.

As test specimen is surrounded by coils from outside, inspection of entire circumference will be done with equal sensitivity.

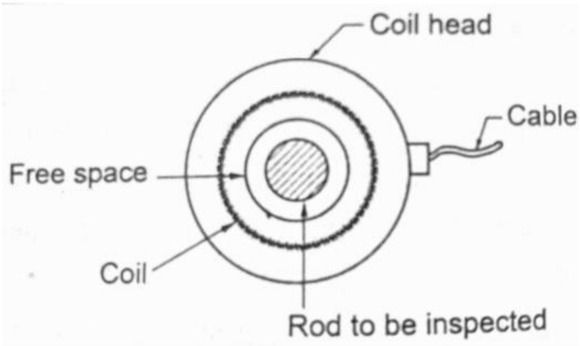


Figure. Encircling Probes

10. Pencil Probes

Pencil probes are highly portable and it is held between the fingers like pencil to conduct inspection of test specimen to identify the defects.

They are available with a straight or bent shaft which facilitates the inspection of small diameter bores.

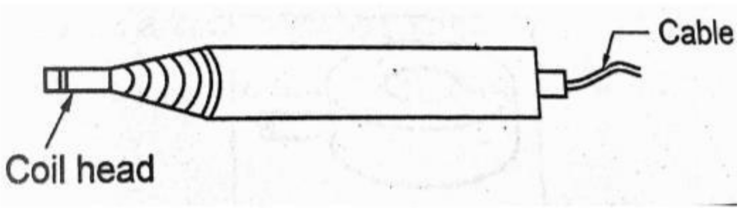


Figure. Pencil Probes

MAGNETIC SENSORS IN EDDY CURRENT TESTING

The selection of the most suitable sensor type for eddy current testing depends on some parameters, including the magnetic field range, the operating frequency band and the dimensions.

Few of the magnetic sensors used in eddy current testing are:

1. Magneto resistive sensors,
2. Hall effect sensors, and
3. Superconducting Quantum Interference Devices (SQUIDS).

1. Magneto Resistive Sensors

Magneto resistive sensors are magnetic field transducer that exhibits a linear change in electrical resistance under an external magnetic field.

Two types of magneto resistive sensors used in eddy current testing are:

1. Spin Valve (SV) sensor, and
2. Magnetic Tunnel Junction (MJT) sensor.
3. SV magnetometers are spin-valve transistors used as magnetic field sensors and have a ferromagnet semiconductor hybrid structure.
4. The magnetic tunnel junctions are based on a spin dependent tunnelling effect.
5. Magneto resistive sensors can be used in eddy current testing to detect the secondary field from the eddy currents. These sensors provide high sensitivity over frequencies up to 100MHz and high resolution due to miniaturization.
6. The main disadvantage of magneto resistive sensors is the high temperature co-efficient.

2. Hall Effect Sensors

1. Hall effect sensors can detect magnetic fields from eddy currents and can be used in eddy current testing.
2. Hall voltage is proportional to the current flowing through the conductive rectangle and perpendicular to the conductor. The magnetic induction
3. The Hall devices are used mainly in the mT range (mT - milli Tesla; unit of flux density) and can be easily miniaturized and integrated within microelectronic circuits.

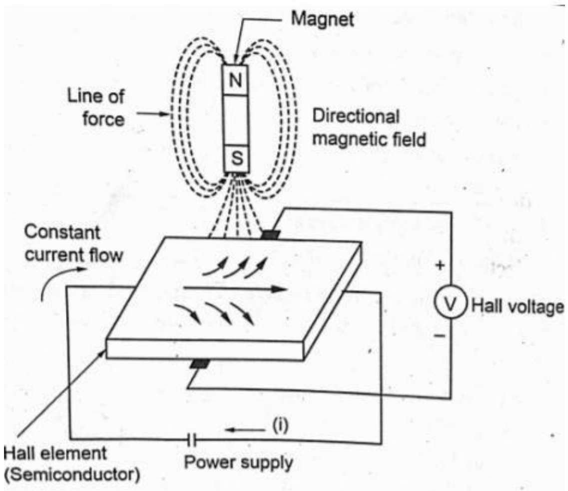


Figure. Hall Effect Sensors

The main disadvantages of the Hall effect sensor are limited sensitivity to silicon and the relatively large offset. The measuring accuracy is much lower than magneto resistance based sensors.

3. SQUID Devices

Superconducting Quantum Interference Devices (SQUIDS) are very sensitive magneto meters designed to measure extremely weak magnetic fields. SQUIDS are based on super conducting loops that contain Josephson junctions. Josephson junction is a type of electronic circuit capable of switching at very high speeds when operated at temperatures approaching absolute zero. SQUIDS are sensors that can measure extremely low magnetic induction levels.

Figure shows the principle of SQUID magnetometer as an eddy current sensor.

In this magnetometer, two Josephson junctions form a super conducting ring. The output voltage is a function of applied flux. A tiny flux signal produces a corresponding voltage swing across the SQUID, which can be measured by a suitable electronics circuitry.

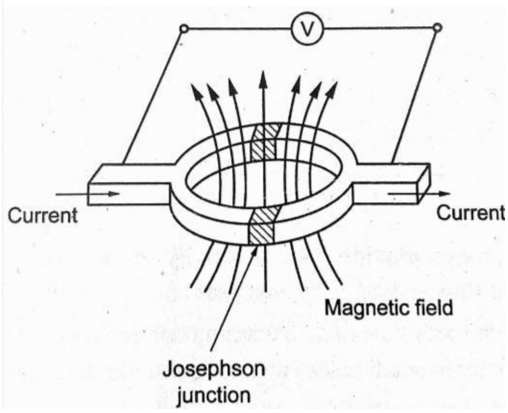


Figure. Principle of SQUID magnetometer

In conventional eddy current systems, where the magnetic field produced by the eddy currents is detected by means of an induction coil, the typical field noise is about – In T √Hz at eddy current frequencies of about 100 kHz.

In some cases, this field noise is too high for certain applications such as the detection of tiny oxide particles, especially if the test materials are highly conductive, such as copper or aluminium. In these circumstances, SQUID magnetometers must be used instead of coil probes. The combination of high sensitivity, even in unshielded environments, high spatial resolution and flat frequency response upto 1 MHz offered by SQUIDS mean that they are powerful sensors for eddy current evaluation,

SELECTION OF EDDY CURRENT TESTING PROBESIMAGNETIC SENSORS

The selection of the most suitable sensor type for eddy current testing is based on some parameters like:

(i) Magnetic field range,
(ii) Operating frequency band,
(iii) Dimensions, and
(iv) Structure.

1. Probes

Coil probes provide high sensitivity to defects when eddy current flow is drastically changed.

Short and small diameter encircling coil probes provide higher sensitivity to small cracks than long and big diameter probes.

Differential encircling probes are suitable to detect discontinuities when a long crack that is parallel to the major axis enters and leave the probe.

Pancake-type rotating probes are used to detect long discontinuities over their full length and able to detect as small as 50 jum. They are more sensitive than encircling coils. But pancake-type rotating probes are not suitable for automatic inspection due to their complexity in rotating systems.

Segment coil probes are specifically designed for controlling the weld seam of welded pipes. The sensitivity of segment probes is higher than encircling probes as they limit the scanning surface to the weld area, where as encircling probes can scan 360 degrees.

Horse shoe-shaped coils are useful in the detection of laminar flaws that pancake type coils cannot detect. Spiral coils provide high sensitivity and arrays of coils permit high speed inspection and obtain high space resolution, reducing the coil size.

Advantages and disadvantages of coil probes:

Advantages	**Disadvantages**
• Simple in construction. • High dynamic range. • Easy to focus on detective area • Low cost	• High induction voltage at the start of the signal. • Difficult to make smaller.

2. Magneto Resistive Sensors

Magneto resistive sensors are more attractive for eddy current testing because of their micro size, high frequency operation and high sensitivity in many areas ignoring the high cost.

Table. presents the advantages and disadvantages of magneto resistive sensors.

Advantages	**Disadvantages**
• Very low field noise to the range. • Micro size. • High frequency operations possible. • High sensitivity.	• Dynamic range is not large enough for few applications • Expensive. • Complex in construction.

3. Array Probes

An eddy current array is in its simplest form a series of singe elements arranged in a row, allowing users to cover a larger area in a single pass than conventional, single-coil probes,

In array probes several individual coils grouped together in one assembly.

Eddy Current Array (ECA) technology provides the ability to electronically drive multiple eddy current coils placed side by side in the same probe assembly. Data acquisition is performed by multiplexing the eddy current coils in a special pattern to avoid mutual inductance between the individual coils.

Multiplexing involves activating and deactivating coils in specific sequence to leverage the probe's width. Due to multiplexing the interference between coils is minimized and maximizes the resolution of the probe.

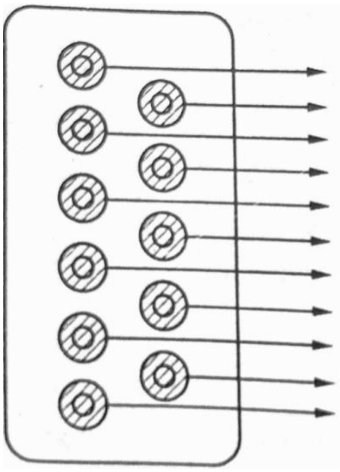


Figure. Arrangement of eddy current array probe

Advantages of Eddy Current Array (ECA) probes include:

(i) Larger area can be scanned in a single probe pass while maintaining a high resolution and faster inspection.
(ii) Less operator dependant, array probe yield more consistent results compared to manual raster scan.
(iii) Improved flaw detection and sizing.
(iv) Can be easily designed to be flexible or shaped to specification to inspect complex shapes. Easy to inspect hard to reach areas.
(v) Easy to analyze because of simpler scan patterns.

Pancake Type Probes

In pancake probes, the coil is arranged in such a way whose axis is perpendicular to the surface of the test piece.

Pancake probes can be either air core coils or ferrite core coils. Ferrites have high permeability and the initial coil impedance is higher than the permeability air core coils.

Pancake type probes are very sensitive to lift off and inclination with respect to the flat surface. These types of probes are used in flat surface inspection.

Pancake type probes are not suitable for detecting laminar flaws as current flow parallel to the surface and they are not strongly distorted.

Pancake probes can be used in either manual automatic eddy current testing. Manual probes are designed especially for testing the surface defects of parts that require supervision and are particularly suitable for the maintenance of aeronautic parts.

When crack occurs on the surface, current flow is strongly altered and the crack can be detected.

APPLICATIONS OF EDDY CURRENT TESTING

Eddy current testing is a fast, accurate, and highly reliable method for determining compositions, surface detects of various components and thickness measurement applications.

Typical applications of ECT include:

1. Material property determinations

(a) Heat treatment evaluations
(b) Hardness
(c) Impurities
(d) Chemical compositions
(e) Corrosion damage

2. Thickness measurements

(a) Thin sheet metal
(b) Foil
(c) Paints
(d) Anodic coatings
(e) Thin insulation
(f) Rocket motor lining

3. Flaw detection

(a) Testing of casted, welded, forged and rolled products.
(b) Detection of cracks or discontinuity in bolts, nuts, holes.
(c) Inspection of railway components.
(d) Determining defects in aerospace parts.
(e) Inspection of tubes of heat exchanger, boiler etc.

Some Practical Applications of Eddy Current Testing

1. Detection of Surface Breaking Cracks/Discontinuities

Eddy current testing is an excellent method for detecting surface and near surface detects. Detects such as cracks are detected when they disrupt the path of eddy currents and
Weaken their strength.

The sensitivity of eddy current inspection to detect surface discontinuities depends on factors such as type of material, surface finish and condition of the material, the design of the probe.

For surface flaws, the frequency should be as high as possible for maximum resolution and high sensitivity

For subsurface flaws, lower frequencies are preferred to set the required depth of penetration and these results in less sensitivity.

Highly conductive or ferromagnetic materials require the use of an even lower frequency to arrive at some level of penetration.

The basic steps involved in application of identifying surface breaking cracks are presented below:

Step 1: Selection of Instrument and Probe

The eddy current testing instrument includes the basic devices such as an oscillator, probe/test coil, signal processing and display.

To test surface cracks, pancake probe or surface probe is preferred.

Step 2: Selection of Frequency to Produce the Desired Depth of Penetration

In eddy current testing, depth of penetration depends on frequency, conductivity and permeability. The only variable is frequency and other two parameters are defined by the 3.81 specimen material to be tested.

High frequency is used for surface cracks and low frequency is used to locate deeper cracks. ✓
General guideline for frequency selection is shown in

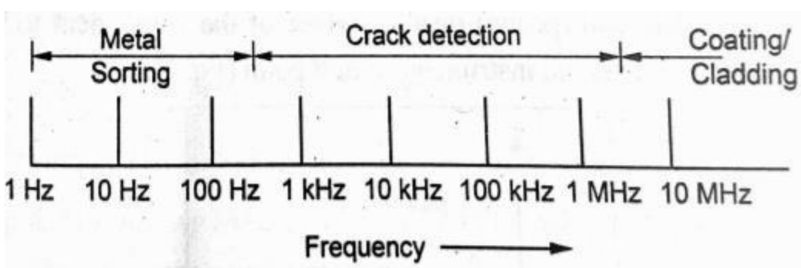


Figure. General guidance for selection of frequency

Step 3: Using Calibration Standard to Adjust Instrument to Recognize the Defect Easily

Reference standards are employed to establish quality control checks for uniformity of response, which can be related to the minimum size of the crack/defect to be detected.

Calibration standard material should have almost the same composition as the test component. Slots are machined by EDM process to different depth ranging from 0.2 to 1.0 mm. The slot width is standardized to 0.1 mm.

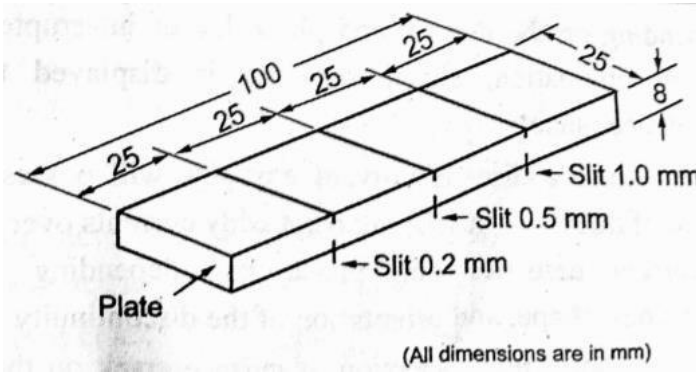
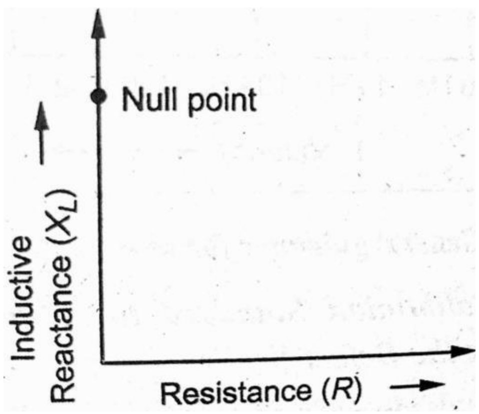


Figure. Type of standard reference

Step 4: Placing the coil Probe and setting the Instrument to Null Point

Place the coil (probe) on the surface of the component to be tested and set the instrument to null point.



Step 5: Scanning the Surface by Moving the Probe in a Pattern

When the probe is moved over the surface of the specimen, eddy current strength is altered due to presence of crack. Depending on the density and phase lag of interrupted eddy current circulation, signal response is displayed through impedance plane.

In fact, since a discontinuity of any size will possess some degree of thickness, it will interrupt eddy currents over a range of current densities and phase lag, depending on the dimensions, shape, and orientation of the discontinuity. Fig. 3.58 shows the inspection of surface crack on the given plate.

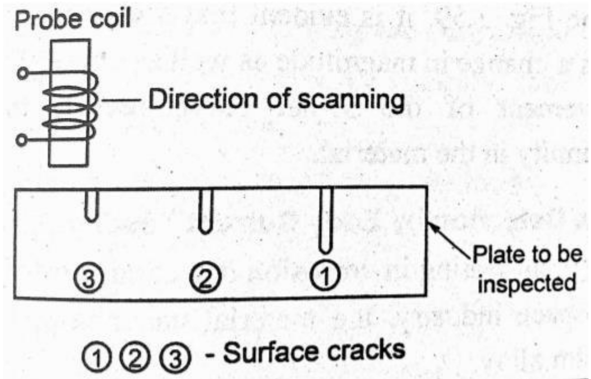


Figure. Surface crack detection by eddy current testing Step 6: Monitoring the Signal for a Change in Impedance

The impedance diagram shown in depicts the effect of crack depth from the surface. With increasing depth of crack from the test surface, the Fig. . Impedance diagram impedance locations are:

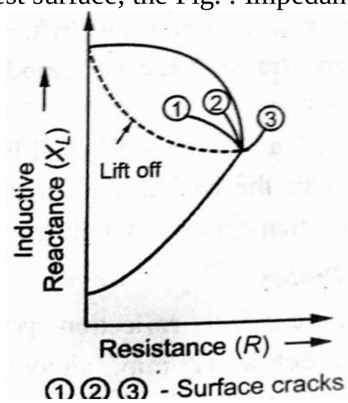


Figure. Impedance diagram

Surface crack (1) - Nearer to the surface
Surface crack (3) -Crack at greater depth

From the Figure it is evident that a change in impedance includes a change in magnitude as well as phase. The direction of movement of the signal curve reveals the possible discontinuity in the material.

2. Corrosion Detection by Eddy Current Testing

Eddy current testing in corrosion detection is extensively used in aerospace industry, the material under inspection will be aluminium alloy.

Corrosion in steel tubing also detected with eddy current testing with suitable modifications. The basic steps involved in corrosion detection by eddy current testing are given below.

Step 1: Selection of Instruments

Instruments with high gain and low drift, preferably operating in the reflection (transmit-receive) mode is preferred for corrosion detection.

The availability of a low pass filter (LPF) is also a useful feature that reduces the background noise that appears with some probes and often appears at high gain settings.

Step 2: Selection of Probes

The best probes are usually reflection spot/surface types with small diameters below 12 mm, although larger sizes are sometimes used to cover larger areas.

Special low noise, high gain reflection models are specially designed for aluminum corrosion detection.

Step 3: Reference Standards

Calibration can be done using a step wedge type of reference standard of similar conductivity and thickness as the areas to be inspected. Areas of reduced thickness of 10%, 20% and 30% are the most common.

Step 4: Placing the Probe and Setting the Instrument

Place the probe on the surface to be inspected for corrosion and the instrument is set for air point.

Step 5: Scanning the Surface by Moving Probe

When the probe is moved over the surface of the place, eddy current strength is altered due to thinning of the metal in corroded location.

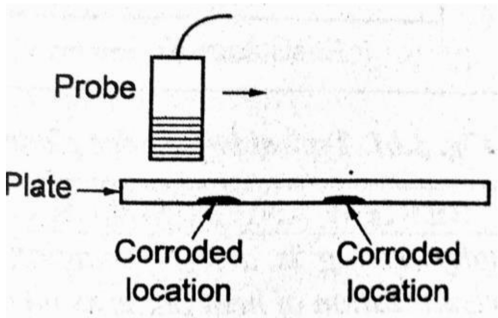


Figure. Inspection of corrosion on the given plate

Step 6: Identifying Thinning of Metal due to Corrosion by Impedance Plane

Figure shows the typical impedance plane, with the inductive reactance (XL) resistance (R) as coordinates, with the probe in air, the dot is at the top of the conducting curve, and it moves down along the curve for increasing material conductivity with point B.

Staring at point B, a reduction in thickness will follow the thickness curve upwards. If there is a thickness reduction the dot will move from B to C as the probe moves over the corrosion spot.