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EDDY CURRENT TESTING
Module 6

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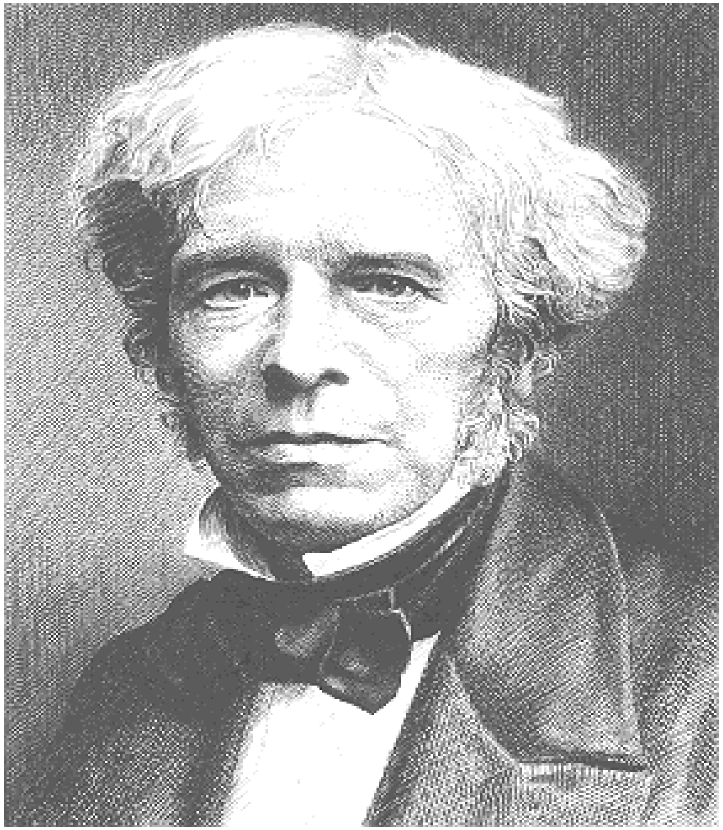
Introduction

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

- Whenever relative motion occurs between a metal conductor and magnetic lines of force, electric currents are induced in the surface of the metal conductor.

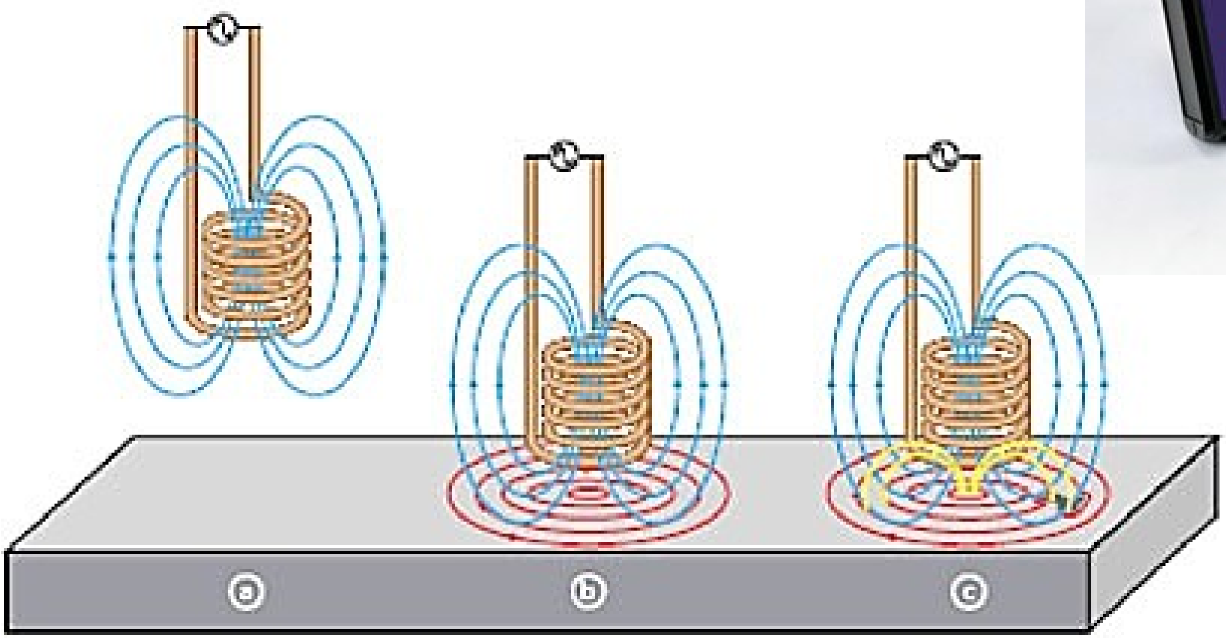
History of EC

- Eddy current testing has its origins with Michael Faraday's discovery of electromagnetic induction in 1831. Faraday was a chemist in England during the early 1800's and is credited with the discovery of electromagnetic induction, electromagnetic rotations, the magneto-optical effect, diamagnetism, and other phenomena.



Michael Faraday (1791 - 1867)

Eddy Current Testing



a—The alternating current flowing through the coil at a chosen frequency generates a magnetic field around the coil.

b—When the coil is placed close to an electrically conductive material, eddy current is induced in the material.

c—If a flaw in the conductive material disturbs the eddy current circulation, the magnetic coupling with the probe is changed and a defect signal can be read by measuring the coil impedance variation.

Eddy Current Testing Introduction

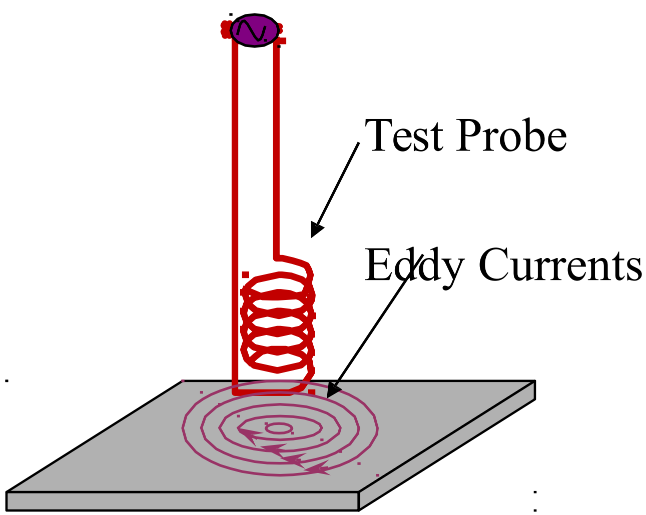
- The eddy current inspection method is applied to the detection of cracks at or near the surface.
- An electrically charged coil carrying an alternate current causes an eddy current to flow in any nearby metal.
- The eddy current may react on the coil to produce substantial changes in its reactivity and resistance, and that reaction is used to pinpoint small cracks or defects.
- Eddy current inspection is accurate for the detection of small flaws or material changes that may not be detected with other inspection methods, and the discontinuities in the casting will give an immediate response on the monitoring equipment.
- The test only can be used with electrically conductive materials.

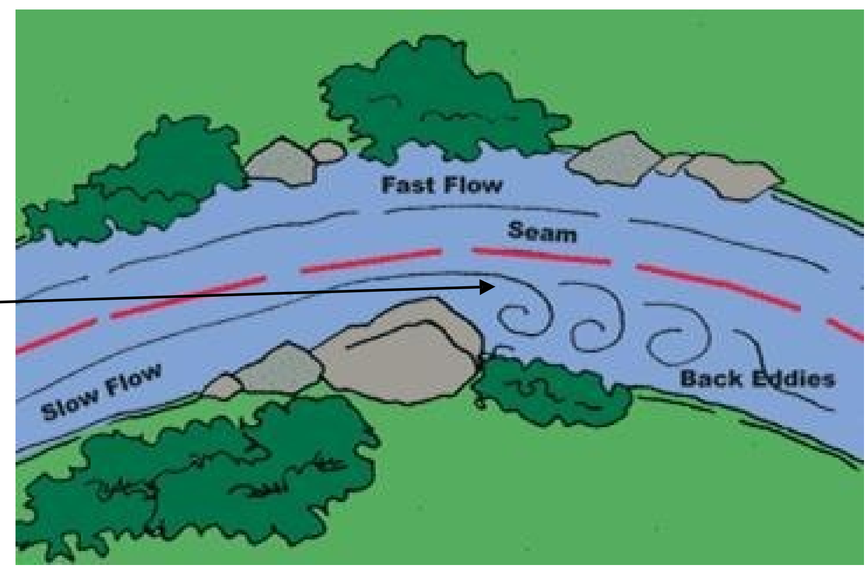
Eddy Current Testing

What is **Eddy Current Testing**?

Generation of Eddy Currents

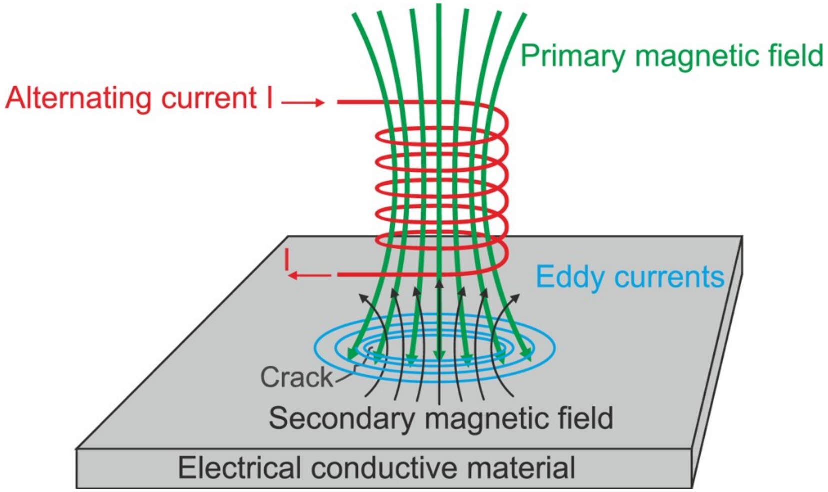
Eddy currents are induced electrical currents that flow in a circular path. They get their name from "eddies" that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right.



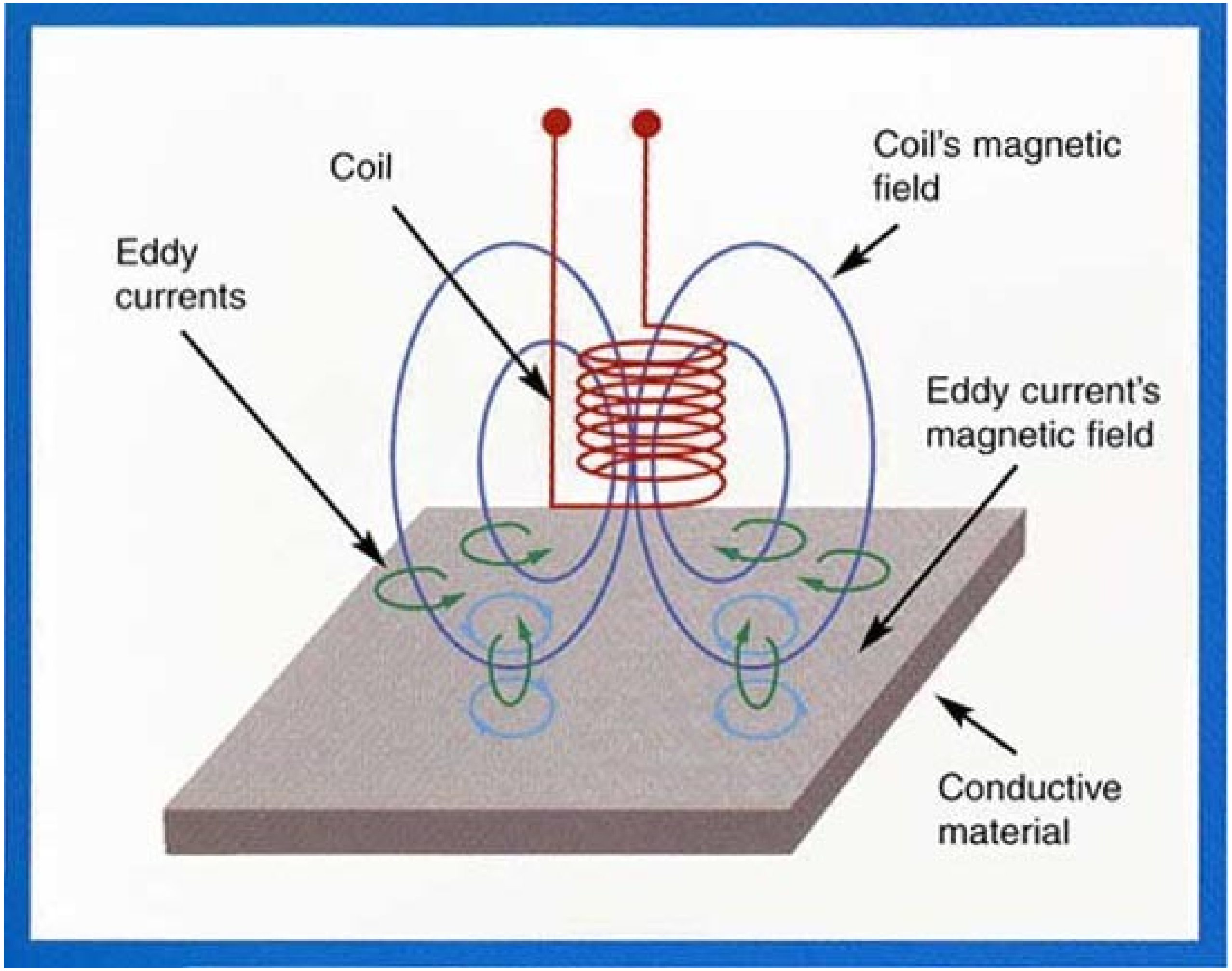


Principles of Eddy Current Testing

- In eddy current testing, an AC of Frequency 1Khz – 2Khz Is made to flow in a coil which in turn, produces an alternating magnetic field around it.
- This coil when brought close to the electrically conducting surface of a metallic material to be inspected, induces an eddy current flow in the material due to electromagnetic induction shown in the figure below.



Principles of ECT



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

Physics aspects of ECT

The factors influencing eddy current testing are

1)Conductivity

2)Permeability

3)Resistivity

4)Inductance

5)Inductive Reactance

6)Impedance

1. Conductivity

- Conductivity is the reverse of resistivity and is the measure of how easily the current can flow through the material.
- Conductivity is often measured by an eddy current technique, and inference can be then drawn about the different factors.
- In general conductivity of material Is affected by the

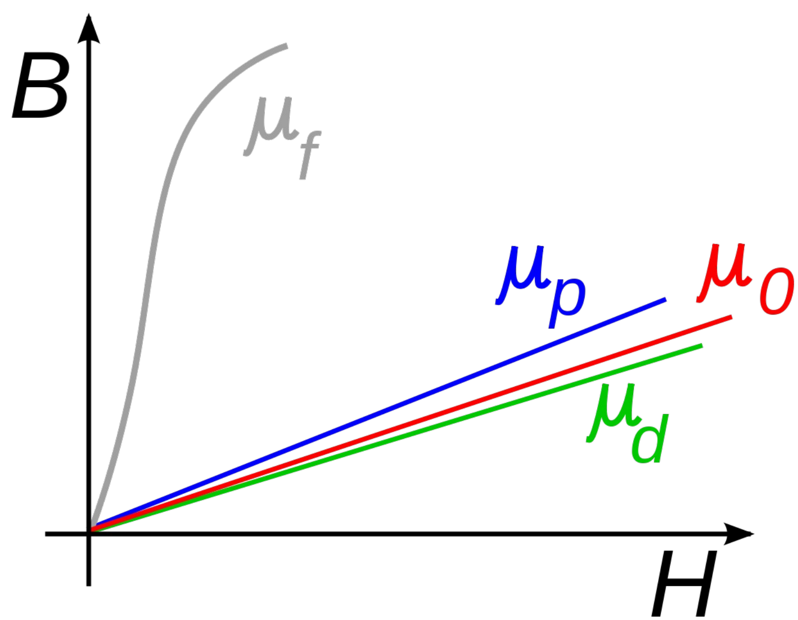
i. Chemical composition

ii. Heat treatment

iii. Temperature

2. Permeability

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



3.Resistivity

- Resistance is the opposition of a body or substance to the flow of electrical current through it, resulting in a change of electrical energy into heat, light or other forms of energy

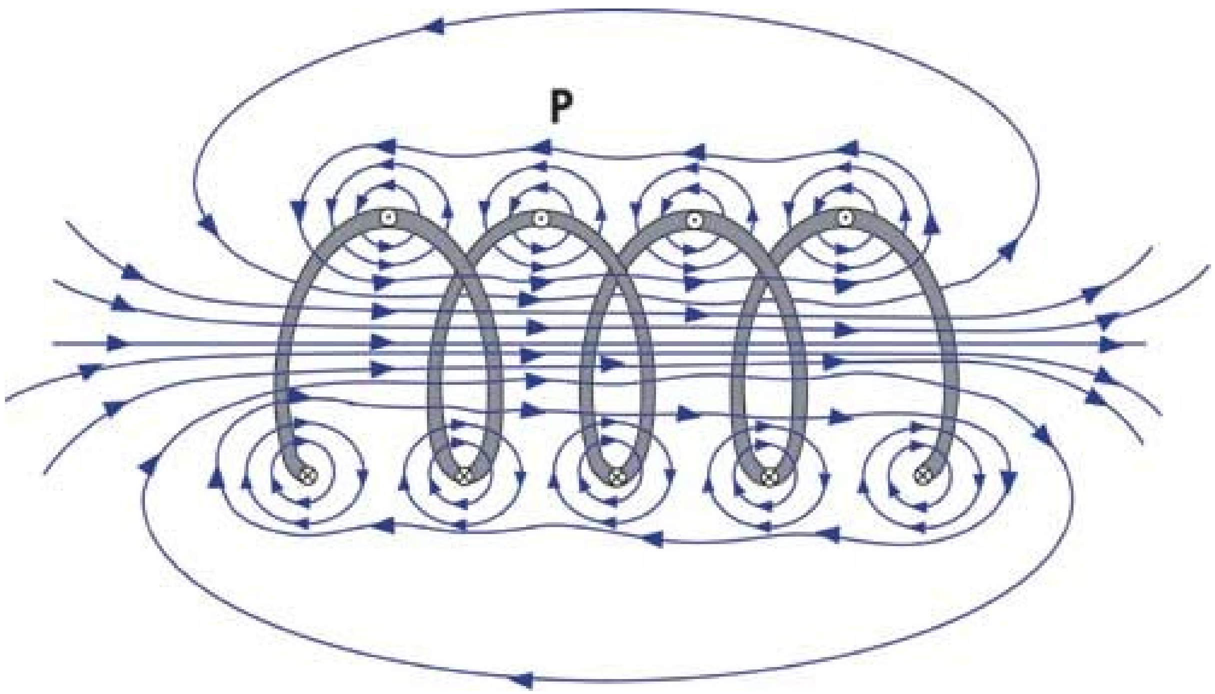
4. Inductance

- Process of generating electrical current in a conductor by placing the conductor in a changing magnetic field is called **electromagnetic induction** or just **induction**. It is called induction because the current is said to be induced in the conductor by the magnetic field.

- When induction occurs in an electrical circuit and affects the flow of electricity it is called inductance

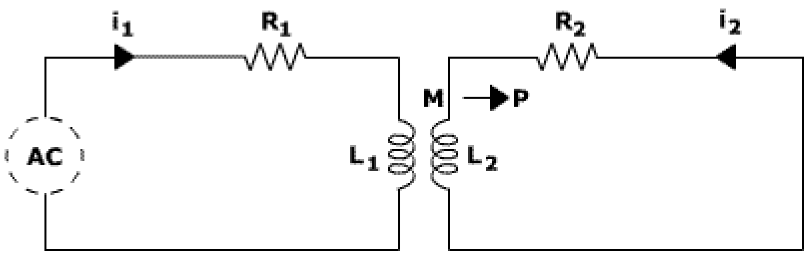
4.1 Self inductance

- The property of self-inductance is a particular form of electromagnetic induction. Self inductance is defined as the induction of a voltage in a current-carrying wire when the current in the wire itself is changing. In the case of self-inductance, the magnetic field created by a changing current in the circuit itself induces a voltage in the same circuit. Therefore, the voltage is self-induced.



4.2 Mutual Inductance

- The magnetic flux through a circuit can be related to the current in that circuit and the currents in other nearby circuits, assuming that there are no nearby permanent magnets. Consider the following two circuits.

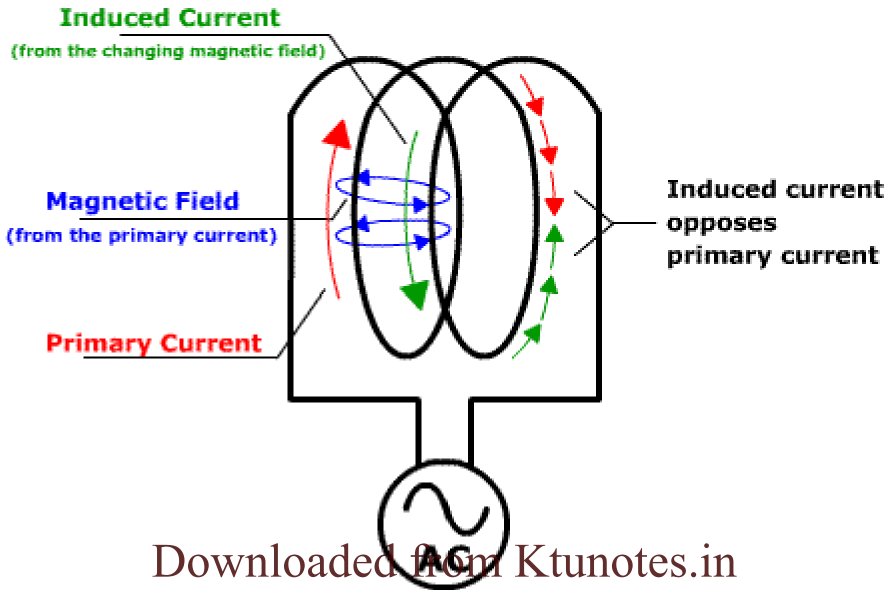


- The magnetic field produced by circuit 1 will intersect the wire in circuit 2 and create current flow. The induced current flow in circuit 2 will have its own magnetic field which will interact with the magnetic field of circuit 1. At some point P, the magnetic field consists of a part due to i1 and a part due to i2. These fields are proportional to the currents producing them.

- The coils in the circuits are labeled L1 and L2 and this term represents the self inductance of each of the coils. The values of L1 and L2 depend on the geometrical arrangement of the circuit (i.e. number of turns in the coil) and the conductivity of the material. The constant M, called the mutual inductance of the two circuits, is dependent on the geometrical arrangement of both circuits. In particular, if the circuits are far apart, the magnetic flux through circuit 2 due to the current i1 will be small and the mutual inductance will be small. L2 and M are constants.

5. Inductive Reactance

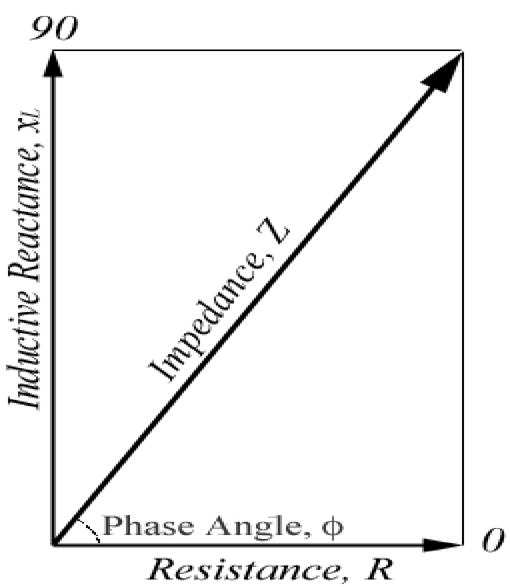
- The reduction of current flow in a circuit due to induction is called **inductive reactance.** By taking a closer look at a coil of wire and applying Lenz's law, it can be seen how inductance reduces the flow of current in the circuit. In the image below, the direction of the primary current is shown in red, and the magnetic field generated by the current is shown in blue. The direction of the magnetic field can be determined by taking your right hand and pointing your thumb in the direction of the current. Your fingers will then point in the direction of the magnetic field. ***It can be seen that the magnetic field from one loop of the wire will cut across the other loops in the coil and this will induce current flow (shown in green) in the circuit.*** According to Lenz's law, the induced current must flow in the opposite direction of the primary current. The induced current working against the primary current results in a reduction of current flow in the circuit.



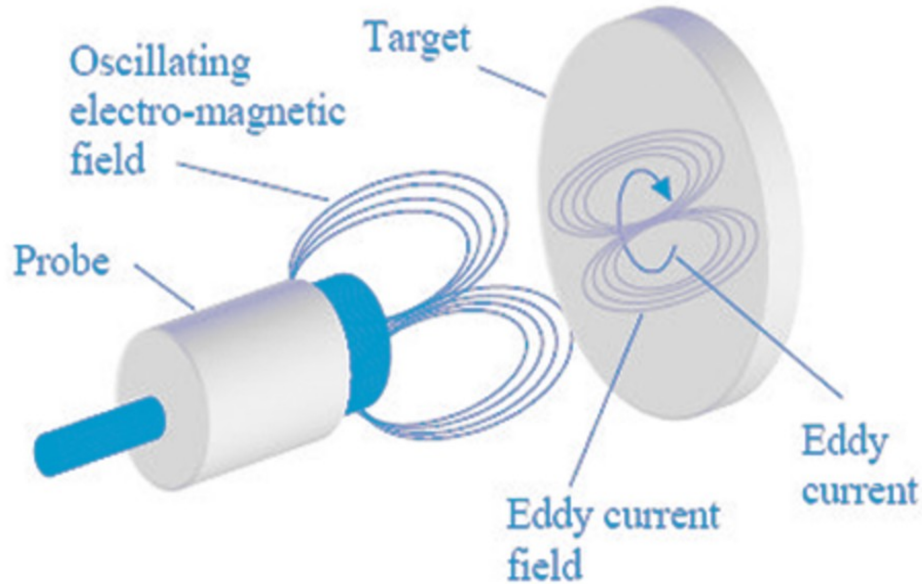
6. Impedance

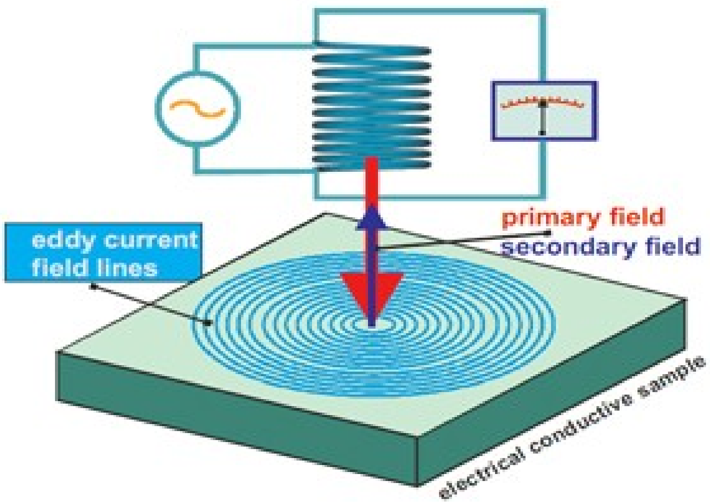
- Electrical **Impedance (Z)**, is the total opposition that a circuit presents to alternating current. Impedance is measured in ohms and may include **resistance (R)**, **inductive reactance (X_L)**, and **capacitive reactance (X_C)**. However, the total impedance is not simply the algebraic sum of the resistance, inductive reactance, and capacitive reactance.

$$Z = \sqrt{\left(X_L^2 + R^2\right)}$$

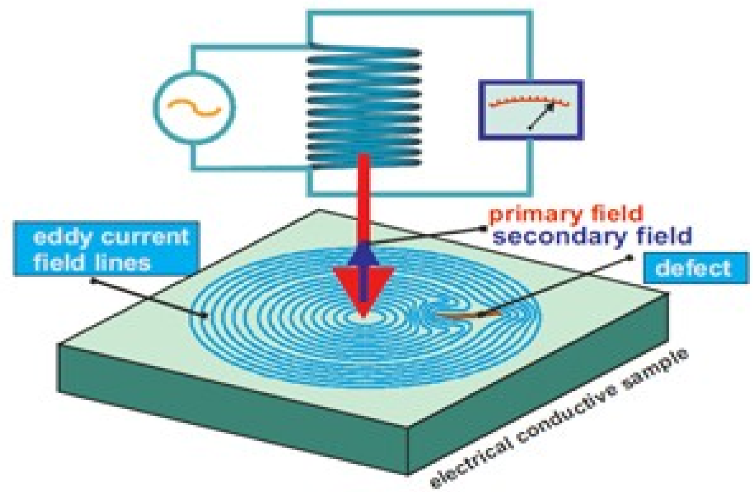


Equipment and accessories for ECT





Coil on a defect-free sample



Coil on a sample with a defect

- Special instruments have been developed in incorporating various methods of detecting and amplifying small impedance changes
- A sine wave oscillator generates sine current, at an specified frequency, that passes through a test coil.
- Since the impedance of two coils is never exactly equal, balancing is required to eliminate the voltage difference between them.
- Once balanced, the presence of a defect in one coil creates a small unbalanced signal which is then amplified, filtered and displayed on the storage oscilloscope after converting to DC signal
- Modern ECT instruments use both amplitude and phase information of the eddy currents.

The common accessories are

1. Coils

Coils are necessary in ECT to produce a sufficient magnetic filed from limited current or a sufficient current from a limited magnetic field

This type of magnetic field from a coil is similar to that from a permanent magnet.

2.Eddy current generation

When the coil is brought in close proximity with the conductive material, the alternating magnetic filed will pass through the material.

The coil can be placed onto the material sideway to the object and eddy current will be induced into the material.

It can be shown that they normally have circular paths at right angles to the primary field parallel to the coil windings.

3. Eddy current detection

The eddy current in the conducting material generate their own magnetic field which in fact opposes and modifies the primary magnetic filed.

This in turn modifies the primary current usually in both phase and amplitude

If the current flowing through the primary field is shown on a display then variations in it can be seen in the presence of defects

4) Probe Selection

The selection of a test coil is influenced by a number of factors

i.Shape of the test specimen

ii.Likely distribution on variables

iii.Accessibility

Lift off Effect

- The distance between a surface coil and 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 effect on sensitivity
- The closer the coupling between the coil and the test specimen, the denser the eddy current filed that can be developed, and thus more sensitivity to any material variable.
- Similarly close coupling increases the sensitivity to lift off effect, noise due to probe nobbles, when encircling coils are used.

Edge Effect

- This refers to the effect that the components edge or Sharpe changes in geometry due to the eddy currents.
- This can be neglected by placing a balancing probe near to the edge and scanning at that distance
- Edge effect is phenomenon that occurs when an inspection coil is at the end of the test piece.
- At that instance, eddy current flow is distorted as currents cannot flow at the edge

Fill Factor

- Fill factor is number which measures how well the test piece fills the coil in external encircling probes.
- Fill factor is calculated by
- Fill Factor=(Diameter $_{\text{test piece}}$)2/ (Diameter $_{\text{coil}}$)2

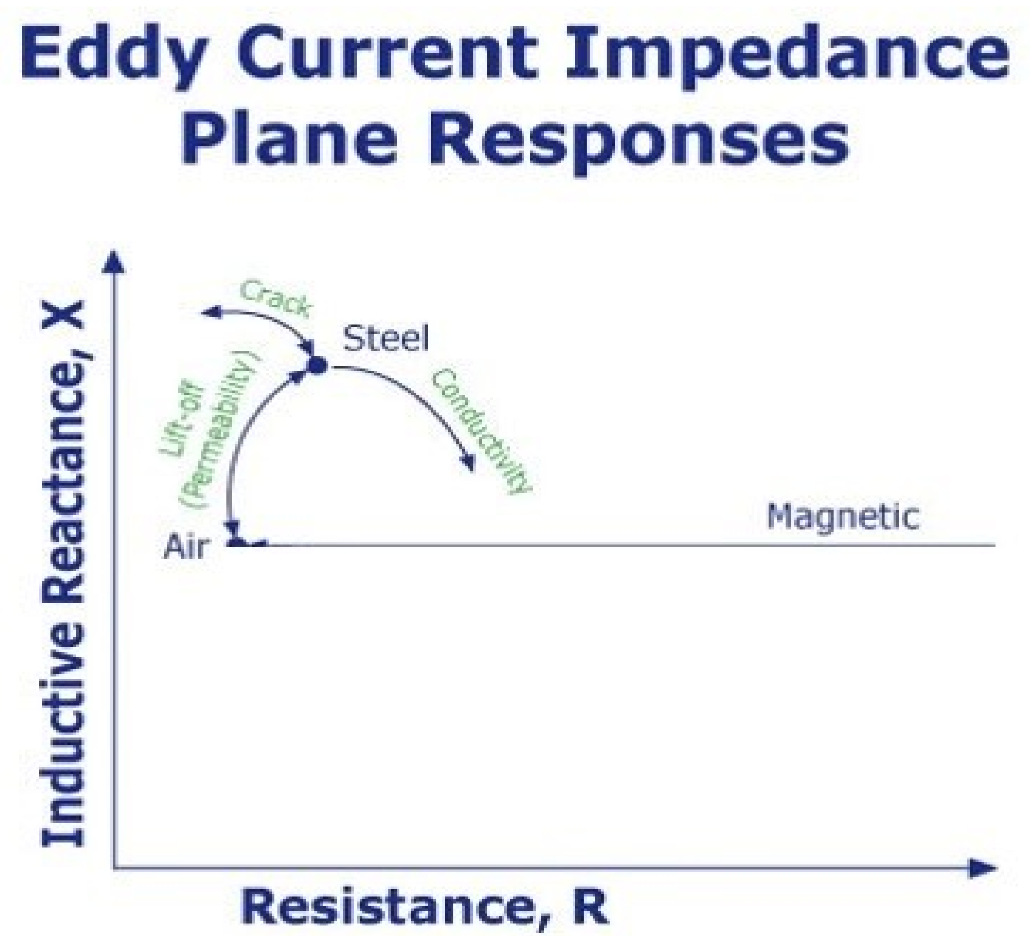
- Fill factor is the ratio of the cross sectional area of the test piece and area of the coil section
- Fill factor should be as near as unity

End Effect

- In eddy current testing, end effect is defined as the disturbance of the magnetic field eddy distribution, impedance due to proximity of the coil to an abrupt change in geometry.

- The end effect is common for cylindrical parts being inspected with encircling or inner diameter coils

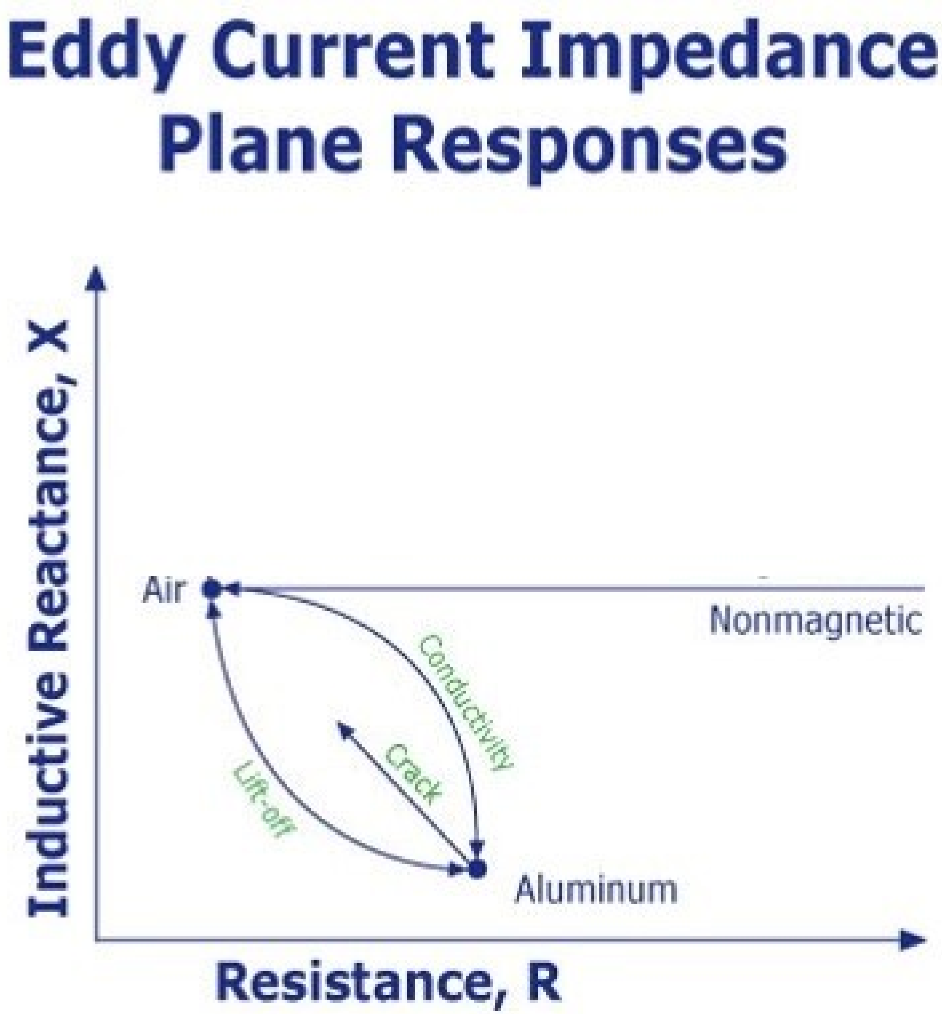
Impedance plane diagram for magnetic material



Impedance plane Diagram

- In an eddy current testing instrumentation, eddy current circuits usually have only resistance and reactance components.
- During inspection, eddy current signals generated during testing of components are displayed by impedance plane diagram.
- The strength of the eddy currents and the magnetic permeability of the test material causes the eddy current signal on the impedance plane.

Impedance plane diagram for non-magnetic material



Depth of Penetration

- Eddy current concentrates near to the surface adjacent to an excitation coil and their strength decreases with distance from coil
- ie, Eddy current density decreases exponentially with depth. This phenomenon is known as the ***skin effect***
- Skin effect arises when the eddy current flowing in the test object at any depth produces magnetic fields which opposes the primary field, thus reducing the net magnetic flux and causing a decrease in eddy current flow as the depth increases.
- It is mathematically convenient to define the "standard depth of penetration" where the eddy current is 37% of its surface value.

Relation Between Frequency and Depth of Penetration

The depth of penetration of eddy current in a material is a critical factor.

For eg- in the case of tube inspection, if the eddy current do not penetrate the wall thickness of the tube , then it is possible to miss the defects.

The depth of penetration of eddy current can be found by the relation

$$\delta = \frac{500}{\sqrt{\sigma \mu f}}$$

Higher the frequency, lower the depth of penetration

For general tube inspection, the frequency used is often the frequency at which the standard depth of penetration is equal to the wall thickness of the tube. This given by the equation

$$f = 250/\sigma x^2 \text{ kHz}$$

Special Applications of ECT

1 Detection of Defects

Defects such as cracks are detected when they disrupt the path of eddy currents and weaken their strength. The images to the right show an eddy current surface probe on the surface of a conductive component

factors such as the type of material, surface finish and condition of the material, the design of the probe, and many other factors can affect the sensitivity of the inspection. Successful detection of surface breaking and near surface cracks requires:

•A knowledge of probable defect type, position, and orientation.

•Selection of the proper probe.

•Selection of a reasonable probe drive frequency.

•Setup or reference specimens of similar material to the component being inspected and with features that are representative of the defect or condition being inspected for.

The basic steps in performing an inspection with a surface probe are the following:

1.Select and setup the instrument and probe.

2.Select a frequency to produce the desired depth of penetration.

3.Adjust the instrument to obtain an easily recognizable defect response using a calibration standard or setup specimen.

4.Place the inspection probe (coil) on the component surface and null the instrument.

5.Scan the probe over part of the surface in a pattern that will provide complete coverage of the area being inspected. Care must be taken to maintain the same probe-to-surface orientation as probe wobble can affect interpretation of the signal. In some cases, fixtures to help maintain orientation or automated scanners may be required.

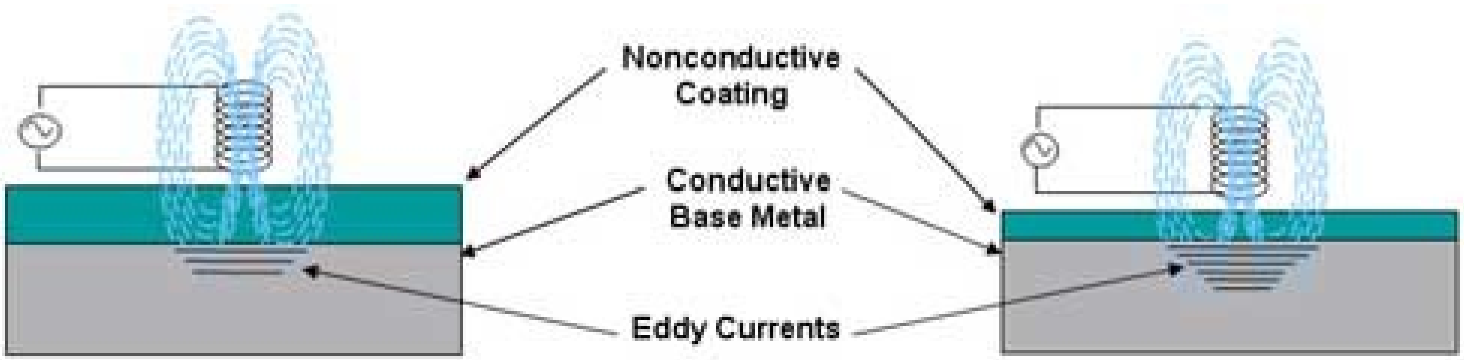
6.Monitor the signal for a local change in impedance that will occur as the probe moves over a discontinuity.

2. Conductivity Measurement

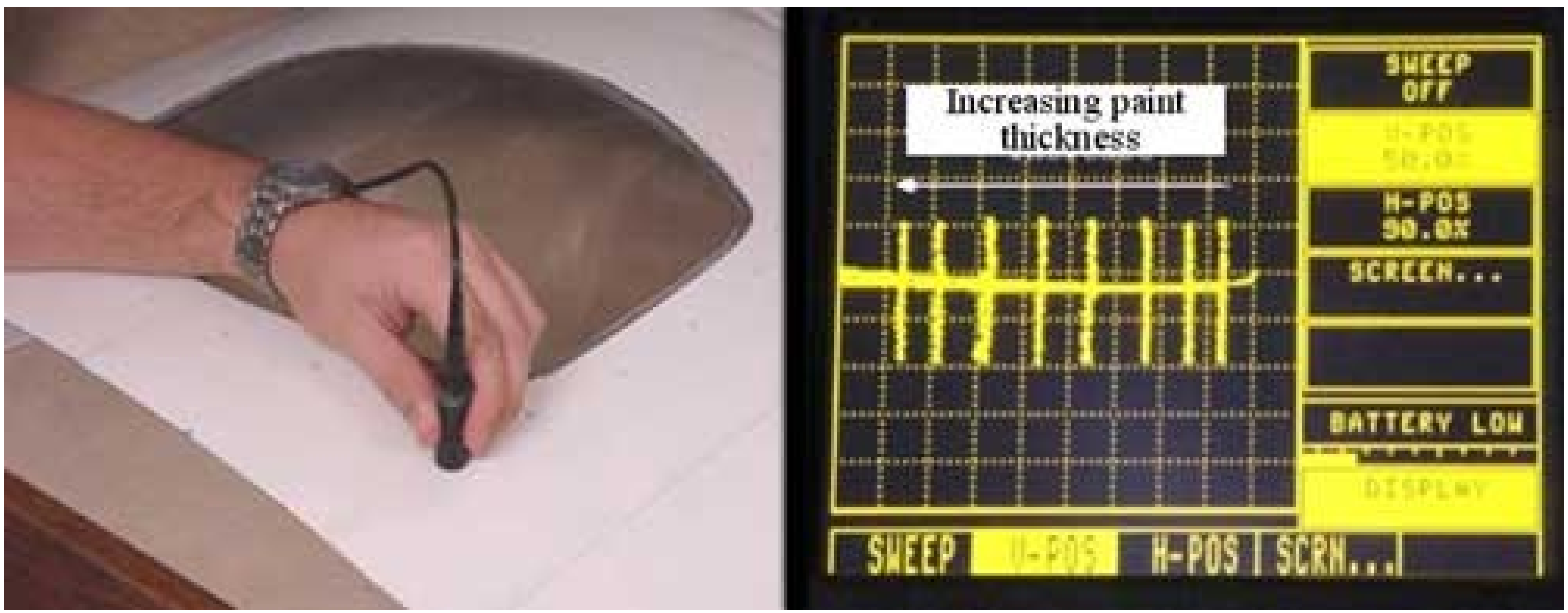
- The technique usually involves nulling an absolute probe in air and placing the probe in contact with the sample surface. For nonmagnetic materials, the change in impedance of the coil can be correlated directly to the conductivity of the material. The technique can be used to easily sort magnetic materials from nonmagnetic materials but it is difficult to separate the conductivity effects from the magnetic permeability effects, so conductivity measurements are limited to nonmagnetic materials.
- It is important to control factors that can affect the results such as the inspection temperature and the part geometry. Conductivity changes with temperature so measurements should be made at a constant temperature and adjustments made for temperature variations when necessary. The thickness of the specimen should generally be greater than three standard depths of penetration. This is so the eddy currents at the back surface of the sample are sufficiently weaker than the variations in the specimen thickness that are not seen in the measurements.

3. Thickness Measurements

The thickness of non-metallic coatings on metal substrates can be determined simply from the effect of lift-off on impedance. This method has widespread use for measuring thickness of paint and plastic coatings. The coating serves as a spacer between the probe and the conductive surface. As the distance between the probe and the conductive base metal increases, the eddy current field strength decreases because less of the probe's magnetic field can interact with the base metal. Thicknesses between 0.5 and 25 µm can be measured to an accuracy between 10% for lower values and 4% for higher values. Contributions to impedance changes due to conductivity variations should be phased out, unless it is known that conductivity variations are negligible, as normally found at higher frequencies.



Fairly precise measurements can be made with a standard eddy current flaw detector and a calibration specimen. The probe is nulled in air and the direction of the lift-off signal is established. The location of the signal is marked on the screen as the probe is placed on the calibration specimen in areas of decreasing coating thickness. When the probe is placed on the test surface, the position of the signal will move from the air null position to a point that can be correlated to the calibration markings.



Advantages of Eddy Current Inspection

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

Limitations of Eddy Current Inspection

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

Applications

- Crack detection
- Material thickness measurements
- Coating thickness measurements
- Conductivity measurements for:
  - Material identification
  - Heat damage detection
  - Case depth determination
  - Heat treatment monitoring

Arigatou gozaimasu