Electromagnetic Testing (ET)
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Electromagnetic testing is a general test category that includes Eddy Current testing (ECT), Alternating Current Field Measurement (ACFM) and Remote Field testing. All of these techniques use the induction of an electric current or magnetic field into a conductive part, then the resulting effects are recorded and evaluated.

Definition
• An NDT method that uses the principal of electromagnetism as the basis for conducting examinations
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Uses for ET

• Crack detection
• Material thickness measurement
• Coating thickness measurement
• Conductivity measurements
  – For material identification, heat damage detection, heat treatment monitoring
• Used by the airline industry for inspection of aircraft skins (surface testing)
• Used by the nuclear power industry for inspection of heat exchanger tubing (volumetric testing)
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Advantages of ET as an NDT method

• Sensitive to small cracks/defects
• Good for inspection of surface/near-surface defects (unlike UT)
• Immediate results
• Portable
• Minimal part preparation
• Can inspect complex shapes and sizes of conductive materials
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Limitations of ET as an NDT method

• Only good on conductive materials (not on magnetic materials)
• Extensive skill and training required for interpretation of results
• Surface finish or build-up may interfere with test results
• Need reference standards for set-up
• Limited depth of penetration
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History
• 1831 - Michael Faraday discovered electromagnetic induction
• 1879 – Hughes recorded changes in the properties of a coil when placed in contact with metals of different conductivity and permeability
• World War II – eddy current testing first put to practical use for testing of materials

Electromagnetic Induction
• Eddy currents are created through the process of electromagnetic induction
  – Eddy currents - induced electrical currents that flow in a circular path
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Current Research
• Photo inductive Imaging (PI) – way to image local stress variations in steel
• Pulsed Eddy Current – used for detection and quantification of corrosion and cracking in multi-layer aluminum aircraft structures – better depth penetration – can be applied to ferromagnetic materials

Properties of Electricity – Electrical Current
• Electrical current is the flow of electrons
• Current is measured in amperes or amps (I)
• 1 Amp = 1 Coulomb (measure of charge) per 1 second
Electromotive Force
- EMF is the force that causes electrons to move
- Measured in Volts (V)
- Sources of EMF include batteries and electric generators

Power and Energy
- Power expressed in Watts
- Energy expressed in Joules
- 1 Joule = 1 Watt – second
  - Amount of energy consumed when one Watt of power acts for one second
Resistance

- Resistance (R) - opposition of a substance to the flow of current
- Depends on the type of material
- Measured in Ohms (Ω)
- Materials with high resistance are good insulators; materials with low resistance are good conductors (copper, gold)
Ohm’s Law
• \( I = \frac{V}{R} \)
  – In words: current = voltage / resistance
• An increase in voltage or a decrease in resistance will result in an increase in current
• A decrease in voltage or an increase in resistance will result in a decrease in current

Induction
• Current passing through a coil generates a magnetic field
• A moving magnetic field induces a current in an electrically conductive material (only present in AC circuits)
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Diagram of Induction
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Inductance/Inductive Reactance

• Inductance (L) – when induction occurs in an electrical circuit and affects the flow of electricity

• Inductive Reactance – reduction of current flow in a circuit due to induction
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Eddy Current Inspection

• Coil used to generate primary magnetic field in a conductive material
• This magnetic field induces eddy currents in the material
• These eddy currents subsequently produce a secondary magnetic field which interacts with the primary magnetic field
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Eddy Current Inspection
• By measuring the change in resistance and inductive reactance of the coil can determine information about the material
  – Electrical conductivity
  – Magnetic permeability
  – Material thickness
  – Condition of material (defect-free?)
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Liftoff
• Distance between coil and conductive material
• Used to make measurements of thickness of nonconductive coatings

Phase Angle
• In inductive/resistive circuits, voltage leads current by 90°
  – Voltage across the inductor is maximized when the current $= 0$
• When inductance is present (not just resistance), voltage and current are out of phase
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More About Eddy Currents
• Closed loops of induced current circulating in planes perpendicular to magnetic flux
• Travel parallel to coil’s winding
• Concentrate near surface
• Strength decreases with distance from coil (skin effect)

Depth of Penetration
• Affected by frequency of excitation current, electrical conductivity, and permeability of specimen
• Decreases with an increase in frequency, conductivity, or magnetic permeability
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Standard Depth of Penetration ($\delta$)

• Eddy current field intensity greatest at surface and decreases exponentially with depth

• Depth at which eddy current density has decreased to 37% of surface value referred to as the standard depth of penetration, $\delta$

• Test frequency often selected to place suspected flaw within one $\delta$
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Eddy Current Depth of Penetration ($\delta$)

- High Frequency
- High Conductivity
- High Permeability

Standard Depth of Penetration (skin depth)

$1/e$ or 37\% of surface density

- Low Frequency
- Low Conductivity
- Low Permeability
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Frequency for Conductivity Measurement
• If test intended to determine a material’s conductivity, the frequency is set to about $3\delta$
• By the time the signal gets to the other side of the material, it is very weak

Phase Lag
• Both voltage and current will have a phase lag (shift in time) with depth
• It is possible to approximate the depth of a defect based on the phase lag
• Depth of Flaw $\approx$ Phase Lag * Standard Depth of Penetration
• Note: this is different than *phase angle* (shift between current and voltage)
Evaluation of Eddy Current Signal

• Signal produced by a flaw depends on both amplitude and phase lag of eddy currents being disrupted

• A small surface defect and a large internal defect can have the same magnitude at $1\delta$, but will have a phase lag of $\sim57^\circ$

Conductivity

• Conductivity of metals is measured in MS/m (mega Siemens per meter)

• A Siemen is the inverse of an Ohm ($1S = 1/1\Omega$)

• Conductivities of metals range from 1-60 MS/m.
Conductivity (continued)

• Conductivity is often expressed as a percentage of the conductivity of a standard sample of copper
• International Annealed Copper Standard (IACS) established in 1913 (100% IACS = 58 MS/m (pure copper))
• Today pure copper has a conductivity that exceeds 100% IACS

Conductivity Measurement

• For example a GE Phasec 3S used for surface inspections and conductivity measurements Measures conductivity in the range of 0.8 – 110% IACS
• Conductivity of various materials
  – Aluminum ~35% IACS
  – Titanium ~ 1% IACS