GE
Inspection Technologies

Eddy Current

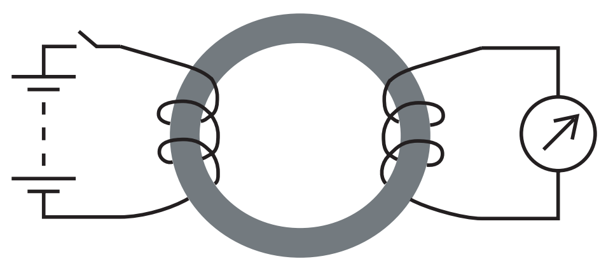
Principles of Eddy Current Testing

History

With the rapid expansion of modern industries such as aerospace and nuclear power generation in the last 50 years, Eddy Current has evolved as a mainstream technology only relatively recently.

The basis for Eddy Current technology has been understood for much longer, starting with the advances in electricity made by Hans Oersted and Michael Faraday in the early 19th Century.

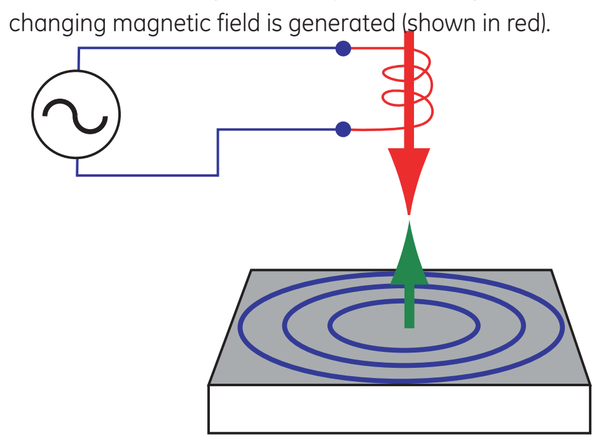
Oersted, noticing that a compass needle was affected when current flowed though a nearby wire, proposed that electric current flowing through a conductor generates a magnetic field around the conductor



Faraday subsequently showed that a changing magnetic field, coupling through a soft iron ring, generates a current in another coil wound on the ring. Later, Maxwell expressed this in his equations for the behaviour of the electromagnetic field, which forms the foundation for Eddy Current technology today.

Principles

When an alternating current is passed through a coil a changing magnetic field is generated (shown in red).



As the coil is placed near to a conductive test piece the magnetic field causes Eddy Currents to flow (shown in blue).

The flow of Eddy Currents depends on the physical and electrical characteristics of the test piece; Eddy Currents avoid cracks, preferring higher conductivity regions. As the Eddy Currents flow in the test piece they generate their own magnetic field (shown in green). This interacts with the magnetic field generated by the coil and changes its impedance. Instruments measure and display these changes in impedance to allow an operator to infer important information about the properties and condition of the test piece.

Applications

The technology offers important advantages for the detection of flaws in metals and has a very broad range of applications. It is truly non-destructive, reliably detecting flaws invisible to the unaided eye. It can penetrate layers of sound material to discover hidden damage which would threaten the serviceability of the material or structure.

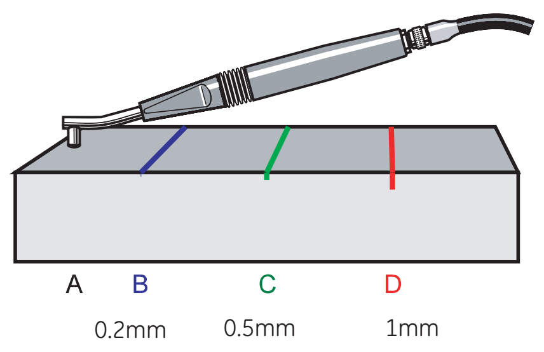
Applications include:

- Surface and near-surface flaw detection
- Inspection of multi-layer structures
- Metal and coating thickness measurement
- Metal sorting by grade, heat treatment and hardness

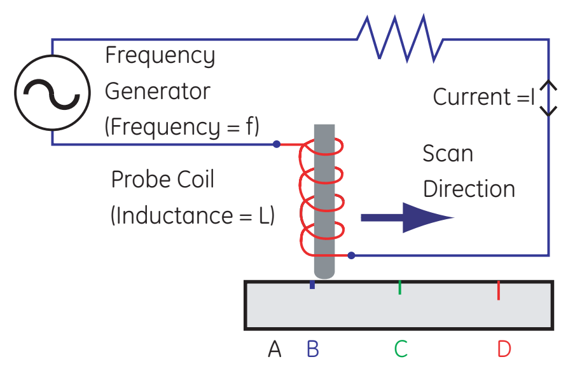
Advantages

- High sensitivity to microscopic flaws
- Gives good discrimination
- High inspection speeds
- Easy to automate
- Easy to learn
- Quick to use
- No contact or couplant required
- No material consumed
- Economical
- Environmentally friendly

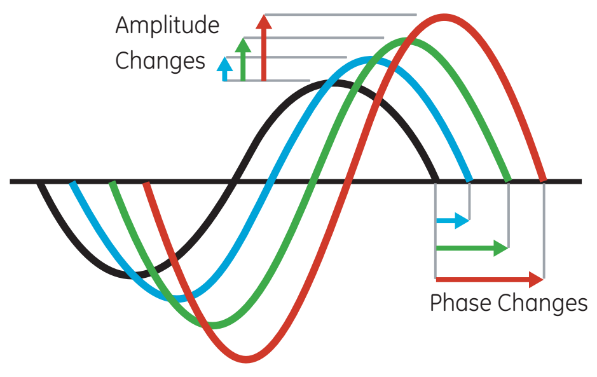
Basic Principles



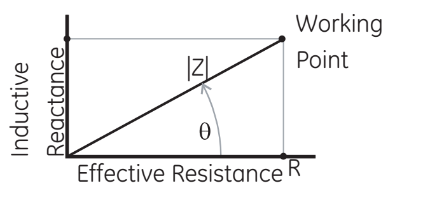
An absolute, shielded, high-frequency probe being scanned across a calibration block.



An alternating current passes through the winding of the probe.

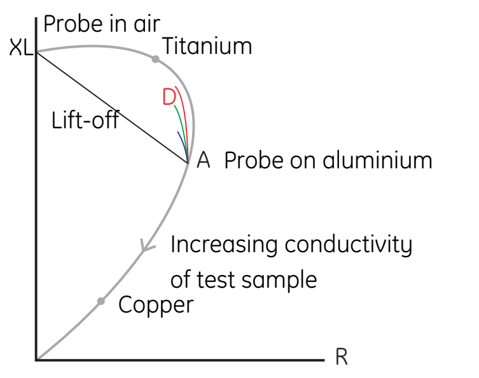


The wave form of the current in the probe changes as it scans across the slots of different depths.

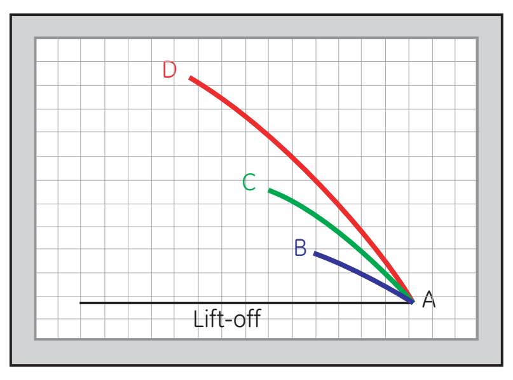


$$|Z| = \sqrt{X_L^2 + R^2} \qquad X_L = |Z| \sin\theta$$
$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right) \qquad R = |Z| \cos\theta$$

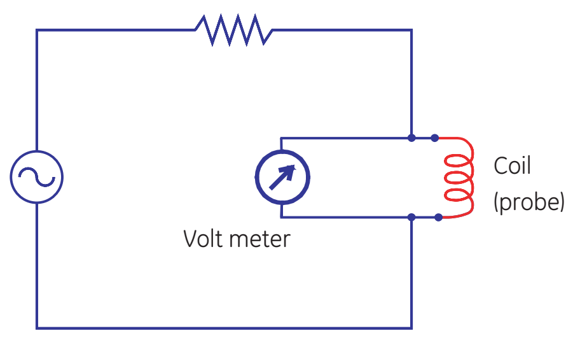
The changes in impedance of the coil in different situations can be shown on a phasor diagram.



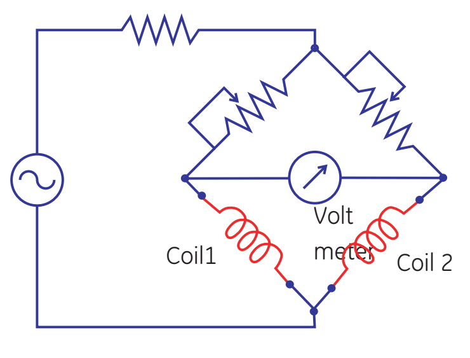
The impedance plane diagram shows what happens as the probe scans across the calibration block and lifts off the surface.



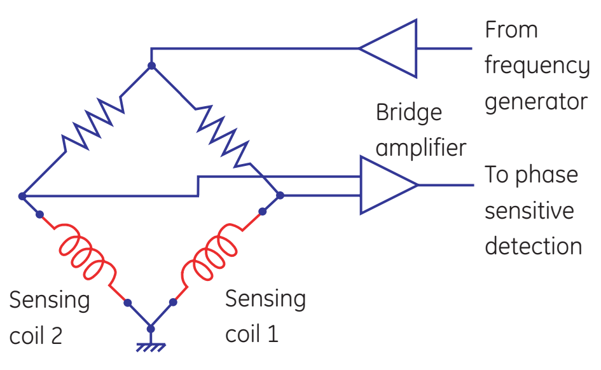
Impedance plane analysis and display of the results of scanning block.



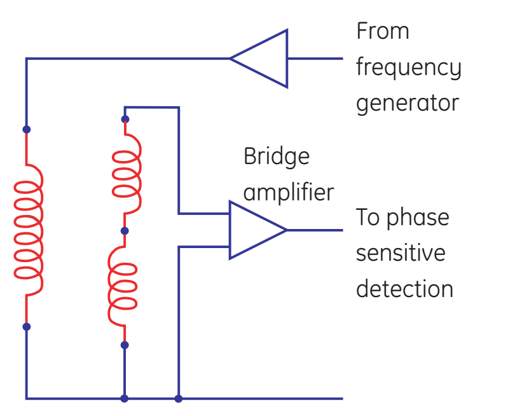
The simplest way of measuring the changing impedance of a coil is to connect a vector voltmeter across it (absolute measurement).



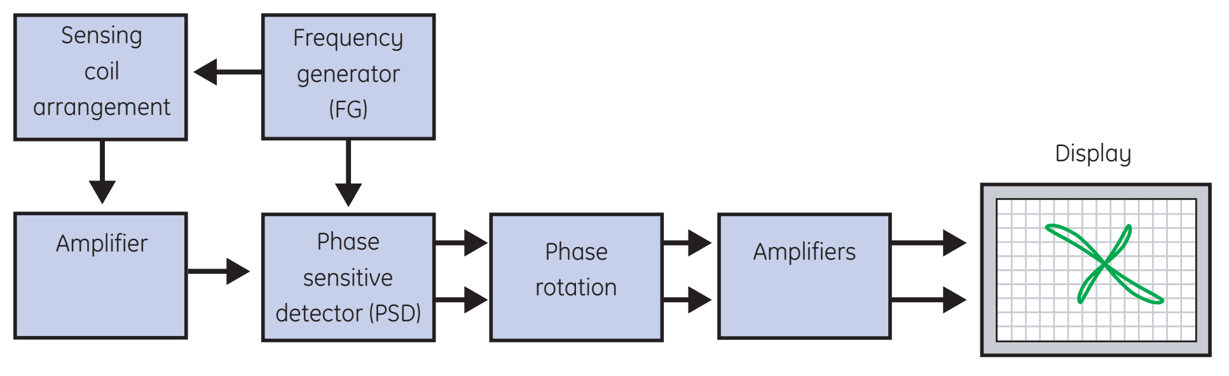
A differential bridge connection allows a vector voltmeter to measure changes or compare differences between samples (differential measurement).



Bridge arranged differential coils for connection to an impedance plane display instrument. If only one coil is used for inspection and the other an inactive load, then it becomes an absolute bridge connected arrangement.



Reflection coil arrangement (also called Driver/Pick-up or Transmit/Receive). Here the driver coil is connected directly to the frequency generator and the pick-up coils wired in anti-phase to the amplifier. This arrangement



A typical arrangement of an impedance plane display instrument

Probes

Absolute Probes

These probes normally consist of a single coil (or winding) that can respond to all changes in the area being inspected. They can be used to detect gradual changes such as metallurgy variations, heat treatment and shape, as well as sudden changes such as cracks.

Differential Probes

Two or more balanced coils are generally positioned close together on the area being inspected, so that they only respond to sharp changes such as cracks. This arrangement is insensitive to gradual changes such as metallurgy variations, geometry and slowly increasing cracks, as well as dramatically reducing the lift-off signal. For sorting or comparison, two separated encircling coils may be used, one containing a known part and the other an unknown part.

Reflection Probes

On this type of probe a driver coil is used to induce eddy currents to flow in the part being inspected and a separate sense coil arrangement (or pick-up) to detect eddy current field changes as the part is scanned. These probes can be differential or absolute, in the case of the absolute probe only one of the two sensing coils is allowed to scan the part. Reflection probes provide a far greater frequency range than that of the commonly used bridge connected coil arrangement.

Unshielded Probes

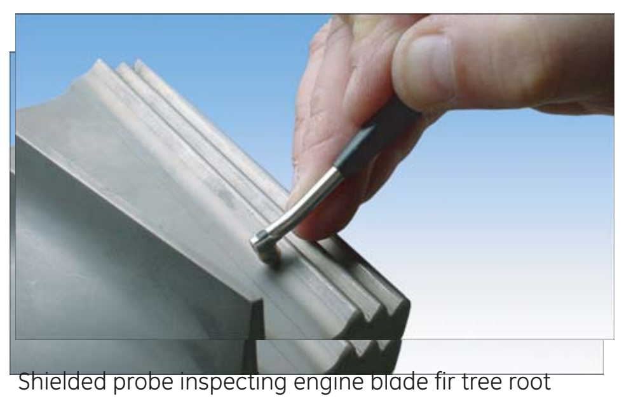
This type of probe is lower in cost to produce and has a wider eddy current field than an equivalent shielded probe. The wider scan width means less passes are required to scan a given area. These probes are more tolerant of lift-off and probe angle, but are affected by edges, fasteners and other nearby discontinuities.

Shielded Probes

In order to restrict the spread of the field from a sensor coil a magnetic shield is placed around it so that the field is narrowly focused at the sensor tip. The resulting shielded probe will be sensitive to small cracks and unaffected by edges, geometry changes and adjacent ferrous material.

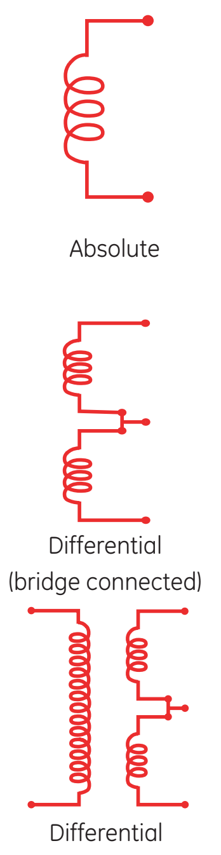
Rotating probe with motor drive

WheelScan probe

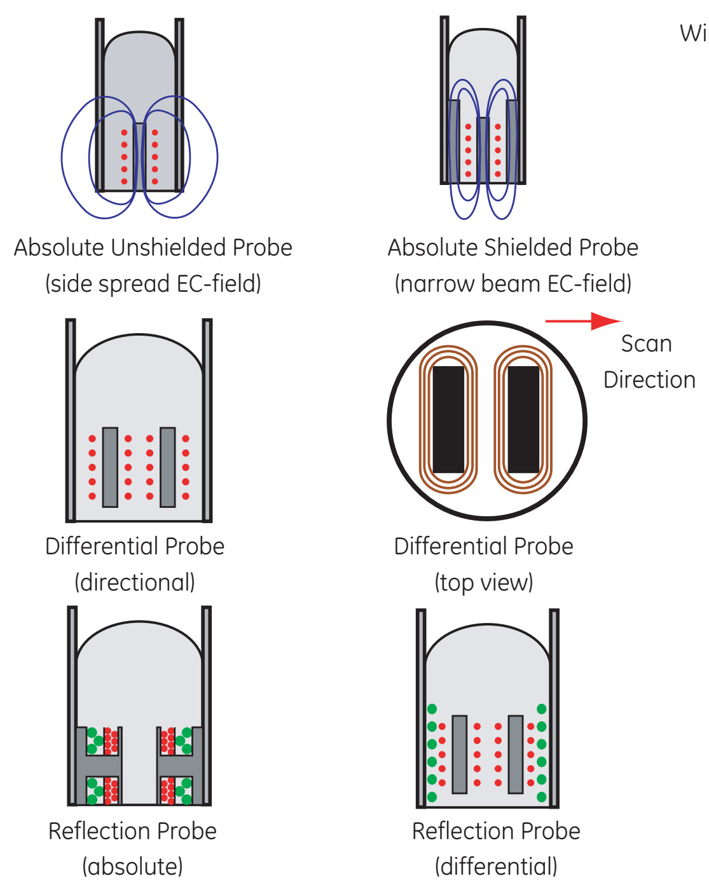


Shielded probe inspecting engine blade fir tree root

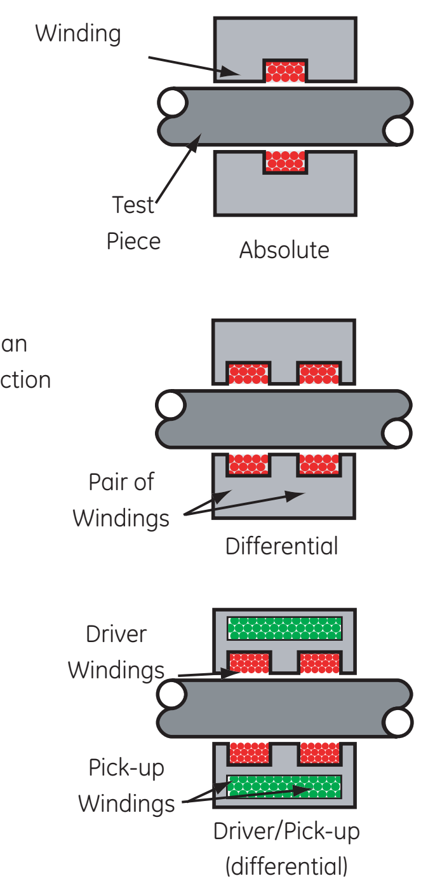
Windings



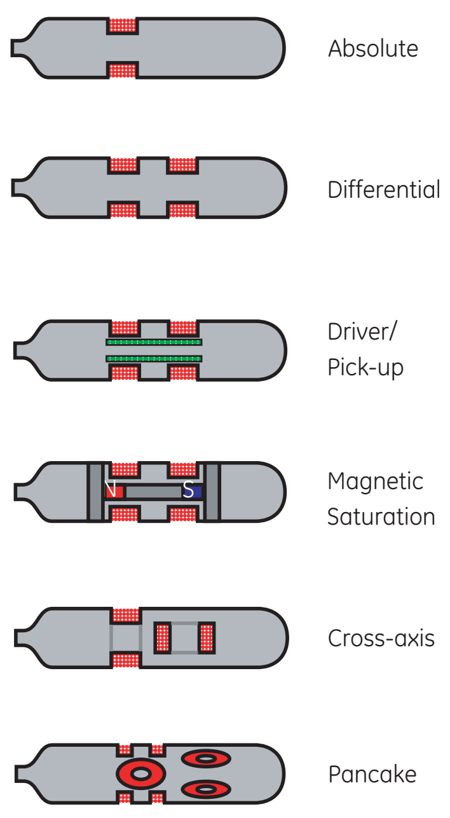
Standard Probes



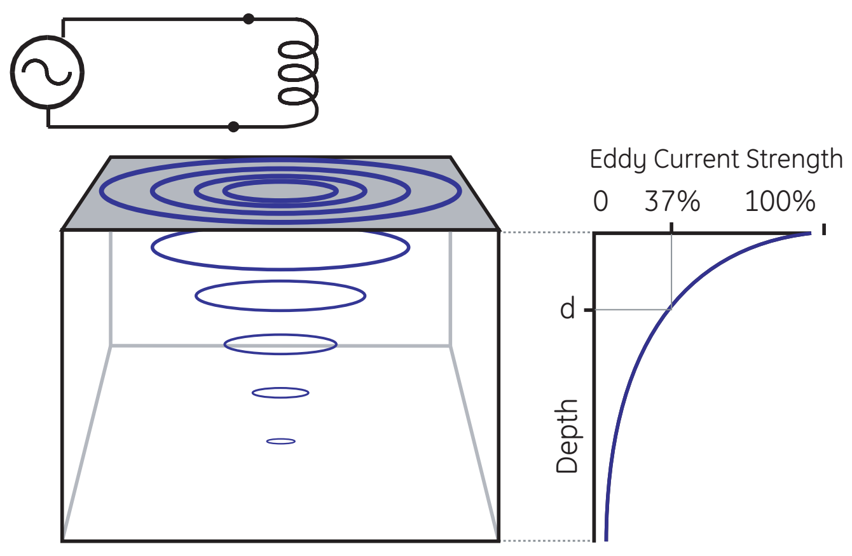
Encircling Coils



ID Probes



Depth of Penetration

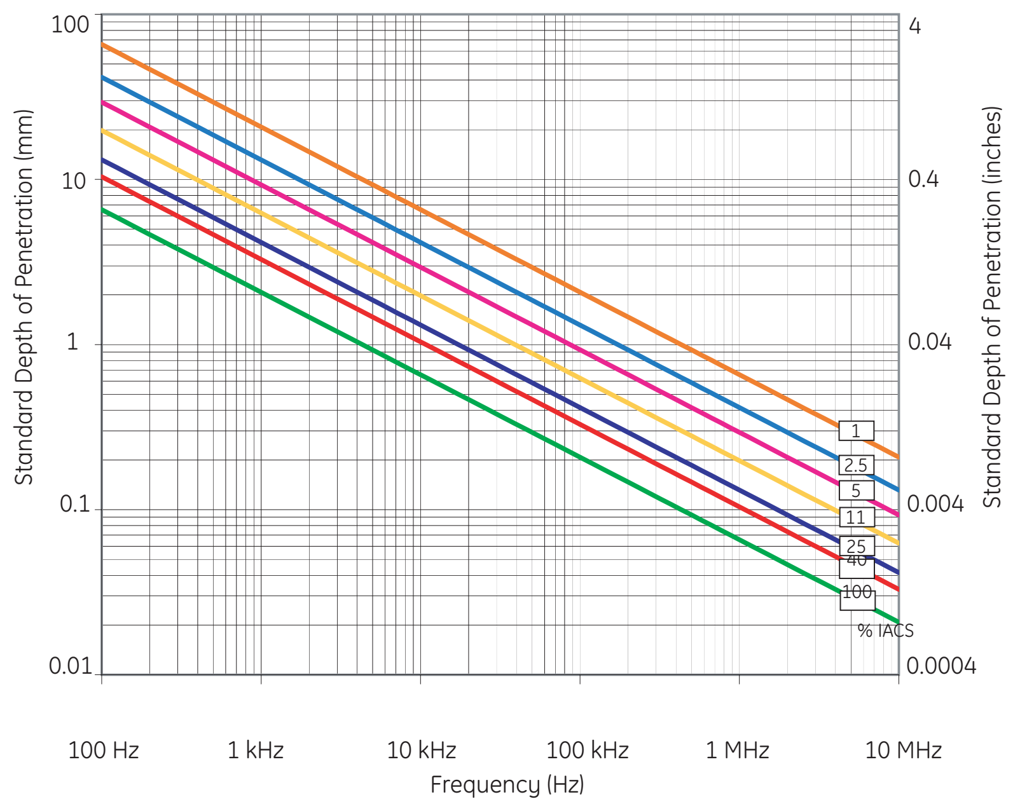


$$\delta = 50\sqrt{\frac{172.41}{\sigma \mu_r f}} \qquad f = \frac{172.41}{\sigma\left(\frac{\delta}{50}\right)^2}$$

s = Conductivity [%IACS]
μ_r = Relative Permeability
f = Frequency [Hz]
δ = Standard Depth of Penetration (mm)

The standard depth of penetration is defined as that depth at which the eddy current strength has dropped to 37% of that at the surface.

%IACS = Conductivity percentage of electrolytic copper (58 . 10^6 Sm^{-1})



Conductivities

Note: Conductivity values shown are approximate and depend on material condition, hardness, heat treatment, temperature and other factors.

Metal Type	%IACS	MSm^{-1}
Aluminium Alloy, 1100	57-62	33-36
Al Alloy, 2014-T3 & -T4	32-35	18.5-23.2
Al Alloy, 2014-T6	38-40	22-23.2
Al Alloy 2024-T3	28-37	16.2-21.5
Al Alloy 2024-T4	28-31	16.2-18
Al Alloy, 7075-T6	32	18.5
Aluminium (pure)	61	35.4
Beryllium	34-43	19.7-24.9
Beryllium Copper	17-21	9.9-12
Brass, 61Cu 37Zn 2Pb	26	15.1
Brass, 61Cu 38Zn 1Sn	26	15.1
Brass, 70Cu 29Zn 1Sn	25	14.5
Brass, 70Cu 30Zn	28	16.2
Brass, 76Cu 23 2Al	23	13.3
Bronze 40Cu 23 2Sn	44	25.5
Bronze 92Cu 8Al	13	7.5
Cadmium	15	14.5
Chromium	13.5	7.8
Copper (pure)	100	58
Cupro Nickel 70/30	5	2.9

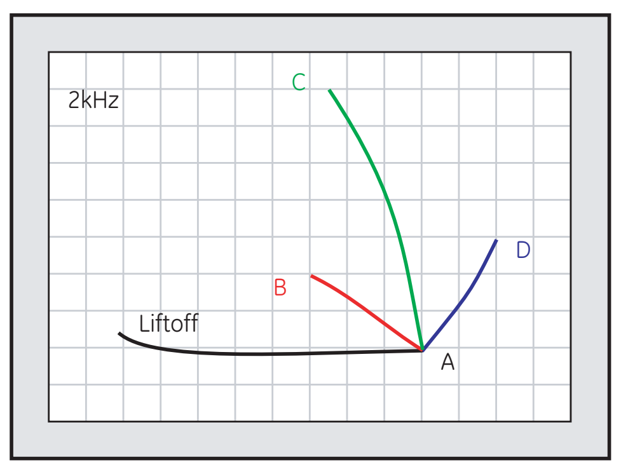
Metal Type	%IACS	MSm^{-1}
Cupro Nickel 90/10	11.9	6.9
Gold	73.4	42.6
Graphite (pyrolitic)	0.43	0.25
Hastelloy	1.3-1.5	0.75-0.87
Inconel 600	1.7	0.99
Lead	8	4.6
Lithium	18.5-20.3	10.7-11.8
Magnesium	37	21.5
Magnesium (Cast Alloys)	9	5.2
Molybdenum	33	19.1
Nickel	25	14.5
Phosphor Bronze	11	6.4
Silver (pure)	105-117	60.9-67.9
Silver (Tin Solder)	16.6	9.6
Silver, 18% Nickel Alloy A	6	3.5
Steel, Stainless (300 series)	2.3-2.5	1.3-1.5
Tin	15	8.7
Titanium	1-4.1	0.6-2.4
Titanium 6914v	1	0.6
Zinc	26.5-32	15.4-18.6
Zirconium	4.2	2.4

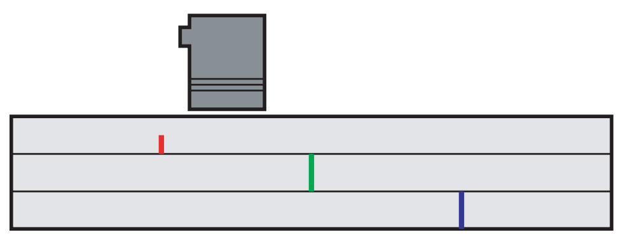
Units

Quantity	Symbol	Unit	Sign
Length		Meter	m
Frequency	f	Hertz	Hz
Electric current	I	Ampere	A
Current density	J		Am^{-2}
Electric potential	U	Volt	V
Resistance	R	Ohm	W
Conductance	G	Siemens	S
Conductivity	s		Sm^{-1}
Electric charge	Q	Coulomb	C
Capacitance	C	Farad	F
Electric flux density	D		Cm^{-2}
Magnetic flux	f	Weber	Wb
Magnetic flux density	B	Tesla	T
Inductance	L	Henry	H
Impedance	Z	Ohm	W
Permeability	μ		$\mu_0 \cdot \mu_r$

To Convert	Multiply By
inches to mm	25.4
mm to inches	0.03937
%IACS to MSm^{-1}	0.58
MSm^{-1} to %IACS	1.724

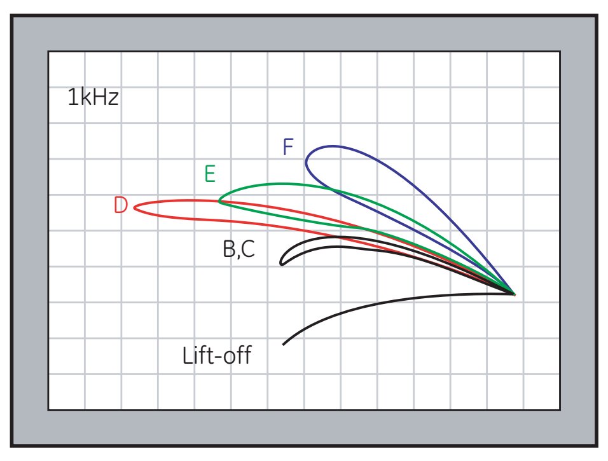
Surface Cracks



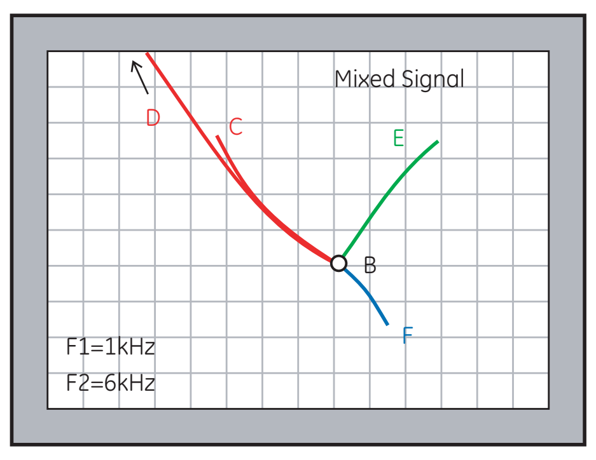


Multi-layer test bock with grooves at different depths

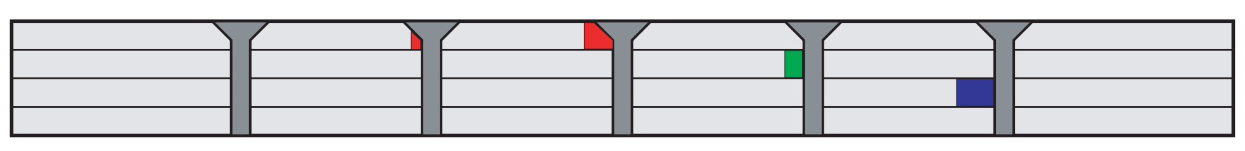
Fastener Inspection



Standard sliding probe

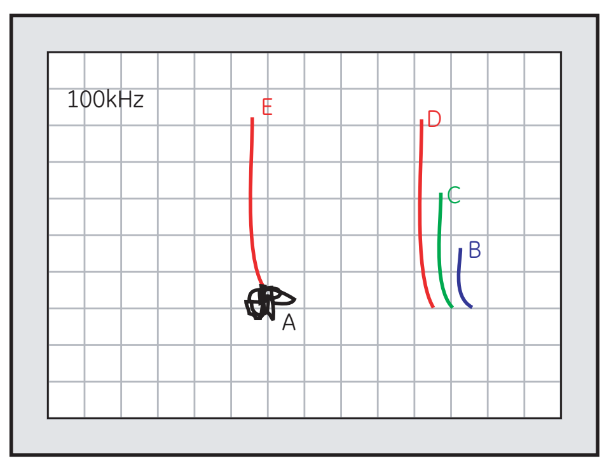


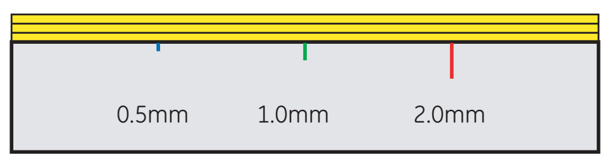
Dual frequency FastScan probe showing depth discrimination



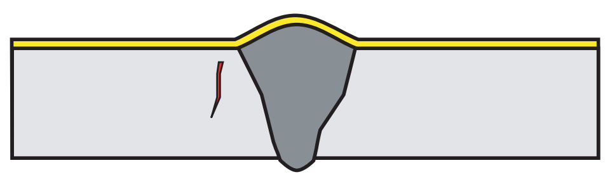
Test block with different cracks in the area of the fasteners

Weld Inspection



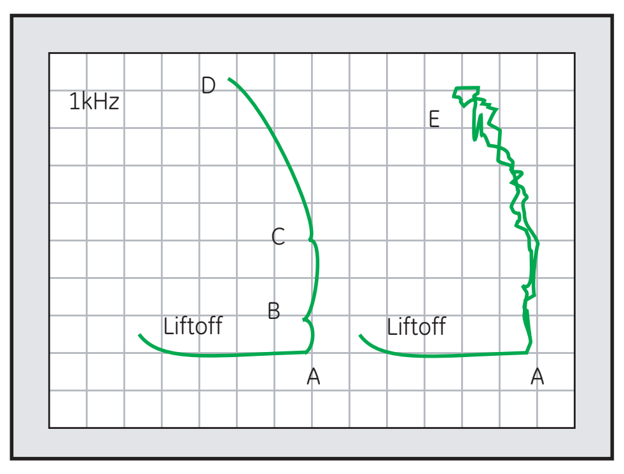


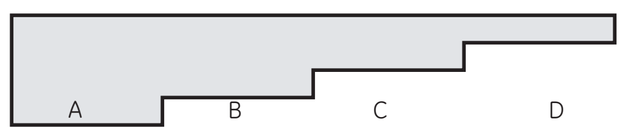
Test block with plastic shims to represent paint



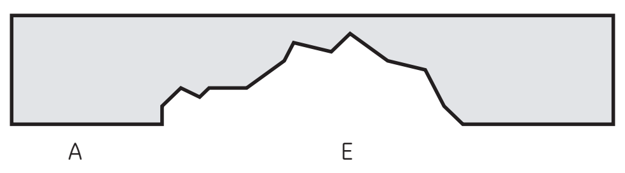
Painted test piece with weld & defect in heat affected zone

Corrosion





Test block with different thicknesses



Test piece with corrosion

Locator being used to check for corrosion in an aircraft

WheelScan - Automatic Wheel Inspection Rig

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