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Investigate of the Effect of Width Defect on Eddy Current Testing Signals under Different Materials

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Abstract

Objectives: Non-Destructive Evaluation (NDE) is the inspection of an object to determine its properties without destroying its usefulness. It is used, for example, to detect cracking in steam generator tubing in nuclear power plants and aircrafts. Eddy Current NDE is a commonly used method of NDE. This study creates a sample calibration block with different materials and investigates the effect of width defects in these materials on the Eddy Current signal**. Method/Statistical**: The materials of the artificial defect block are mild steel, brass and copper with dimensions of 260 mm (length) × 30 mm (width) × 10 mm (height). A total of 12 artificial defects are located 20 mm parallel to the length of the block. The distance of the defect is located in between 1 mm up to 2.5 mm from the surface of the artificial defect block. A weld probe was used to inspect the block. The wire cut machines were utilized to add defects to the sample block**. Findings**: Results prove that the deviation of Eddy Current Testing measurement was influenced by the width and material of the objective. **Application/Improvement:** The results showed that the signal of the Eddy Current was affected by the size of the defect and the type of specimen.

Keywords: Calibration Block, Defect Detection, Eddy Current, Non-Destructive Testing

1. Introduction

Non-Destructive Testing and evaluation is the process of assessing the structural integrity of a material or component without causing any physical damage to the test object[1]. Eddy Current Testing is an effective method to detect fatigue cracks and corrosion in conductive materials because it is cheap and can monitor subsurface defects or defects under insulating coatings without touching the surface of a specimen[2,3].

An Eddy Current is sensitive to many factors. One factor to which it is sensitive is the temperature of the component under inspection, which produces variations in material conductivity. Another source of uncertainty is the changes in the position of the probe field when a part is scanned. This factor produces variations in coupling or changes in the lift-off distance from the probe to the pant. The geometry of the part under inspection can also influence the process; thus, maintaining a normal incidence of the probe field is difficult. Lastly, the frequency of the operation used produces changes in the skin effect observed in conductors, which can dramatically alter the response of the probe to a flaw[4–6]. The response of the pickup coil or receiver coil to an Eddy Current depends on the conductivity and permeability of the test material and the frequency selected[7]. Material permeability and the strength of magnetic induction are influenced by the type of material. Thus, more secondary electromagnetic

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waves are produced in ferrous metals than in non-ferrous metals. Therefore, permeability significantly influences the Eddy Current defect signal[8]. Frequency affects the depth penetration of electromagnetic waves in the material. An electromagnetic wave with a low frequency will have high penetration strength[9,10]. Crack orientation strongly influences the output of the Eddy Current probe. Cracks must interrupt the surface Eddy Current flow for them to be detected. Defects parallel to the current path will not cause any significant interruption and may not be detected[11].

This paper investigates the effect of width defects and material conductivity on the Eddy Current Testing signal. The materials of mild steel, brass and copper have been used with dimensions of 260 mm (length) × 30 mm (width) × 10 mm (height). A total of 12 artificial defects were located 20 mm parallel to the length of the block. The defects were located between 1 mm to 2.5 mm from the surface of the artificial defect block. The effects include the varying signals between different materials.

1.1 Basics of Eddy Current Testing

Eddy currents are generated through electromagnetic induction[8]. A magnetic field develops around the conductor when an alternating current is passed through a conductor. This magnetic field increases or decreases based on the change in the alternating current. If another conductor is kept in close proximity to this field, then the current will be induced in the second conductor. Eddy currents are induced currents that flow in a circular fashion[12,13] as shown in Figure 1.

As described above, in Eddy Current Testing involves exciting a coil with alternating currents that induce eddy currents in the test object. The interaction of these currents with defects can change the exciting field. These variations are detected by measuring a change in impedance of the exciting coil or the pickup coil. As the source moves over a specimen, changes occur in its impedance when it moves over a defect; these changes carry information such as shape, size and the location of the defect. The governing equations describing the material interaction are Maxwell's equations and the solution has a closed form for simple problems or with simplifying conditions[12].

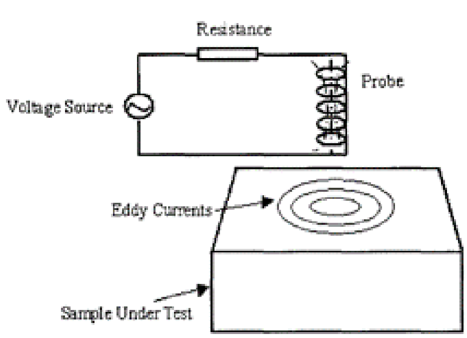


Figure 1. Principle for Eddy Currents.

The differential equations governing the general time-varying fields in regions of conducting materials can be derived from the Maxwell Equations.

The following assumptions are made:

The media are linear and isotropic.

The medium has no free charge in the solution region. The only electric field in the solution region is attributed to the exciting current densities.

The following Equations are therefore true[14]:

$$\mathbf{v}\nabla \, X \, (\nabla \, X \, A^{\rightharpoonup}) = -\sigma \frac{\partial A^{\rightharpoonup}}{\partial t} - \sigma \nabla \boldsymbol{\Phi} \quad (1)$$

$$\nabla^2 \boldsymbol{\Phi} = -\frac{\partial}{\partial t(\nabla \, . \, A^{\rightharpoonup})} \quad (2)$$

Where

υ is the reluctance.

A is the magnetic vector potential.

Σ is the conductivity in S/m.

$\emptyset$ is the electrical scalar potential.

Equations 1 and 2 are the basic field equations that describe the electromagnetic field in linear media.

The lift-off distance is the distance between the coil and the surface. A significant reduction in sensitivity of the EC probe is observed when the lift-off distance increases. This result occurs because of the exponential decrease of the magnetic field in the space between the coil and the specimen. A lift-off of less than 1 mm is commonly used in EC testing. Differential probes are used for lift-off error compensation and temperature change compensation[7,10].

1.2 Eddy Current Inspection Process

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

- Select and setup the instrument and probe.
- Select a frequency to produce the desired depth of penetration.
- Adjust the instrument to obtain an easily recognizable defect response using a calibration standard.
- Place the probe on the surface and null the instrument.

- The probe must be scanned over the surface in a pattern that will provide complete coverage of the area being inspected. Probe-to-surface orientation must be maintained, as the probe wobble can affect the interpretation of the defect signal. In many applications, fixtures are used to help maintain orientation of automated scanners.
- Monitor the signal for a change in impedance that might occur as the probe moves over a defect.

2. Materials and Methods

2.1 Materials

Three different materials have been used to fabricate calibration blocks. Copper was first selected for the specimen because of its high electrical conductivity, which is crucial in the electric and electronics industries. Brass is also an excellent conductor of heat and electricity. A mild steel block is the third choice because the inherent properties of mild steel allow electrical current to flow through it easily without upsetting its structural integrity.

2.2 Construct the Calibration Block

The copper, brass and mild steel materials were used as calibration blocks with dimensions of 260 mm (length) x 30 mm (width) x 10 mm (height). A total of 12 slots of artificial defects with different depths were made by using Surface grinding, Milling process and the EDM wire cut machine. Auto CAD design software was used to design the artificial defect slots. The defect block is illustrated in Figure 2.

2.3 Inspection the Calibration Blocks using a Weld Probe

A weld (differential probe) was used to inspect the materials. The locator menu was first adjusted to the appropriate settings, as shown in Table 1. The positive and negative index points were indicated on the probe by maximizing on the 1 mm notch in the D50 reference block.

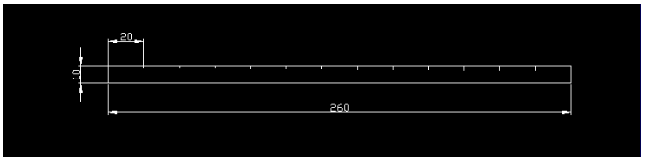


Figure 2. Side view of the defect block.

Table 1. Weld probe settings

Frequency	100 kHz
Gain	50 dB (approx.)
Probe	Bridge
Persistence	Permanent
Phase	Set to 12 o'clock 100% FSH
Spot X/Y	Centre of the screen

The weld probe was calibrated on the calibration block. Figure 3 shows the Eddy Current set. The correct gain, frequency and velocity were considered to inspect all materials and to the signal and result. All results were used to compare the defect signal of the width on different block materials and to measure the variations of the Eddy Current between the brass block, copper block and mild steel block.

3. Results and Discussion

The artificial defect block was measured by using a weld probe. The defect block had 12 artificial defects located 20 mm parallel to the length of the block. The defects were located in between 1 mm up to 2.5 mm from the surface of the artificial defect block. Each slot was measured five times with different widths. The material conductivity of brass was 23.65% based on the IACS. Table 2 shows the conductivity test results of all materials.

3.1 Inspection Results for Mild Steel Blocks

The effect of the width defect with mild steel on Eddy Current Testing signal could be detected by the weld probe. The inspection was conducted by using a frequency of 50 kHz to 100 kHz. The phase was set to 100% FSH and the gain was set to 50 dB (approximate). Table 3 shows the signal of Eddy Current Testing measurements for mild steel with different depths and widths.

Figure 4 shows the different percentages of signals between different widths and depths (1, 1.5, 2 and 2.5 mm) on the mild steel block based on Eddy Current Testing. The results clarify the effect of the width of the defect on the Eddy Current signal.

3.2 Comparison the Effect of Material on the Signal of Eddy Current

The effect of the width defect with brass and copper material on the Eddy Current Testing signal could be detected

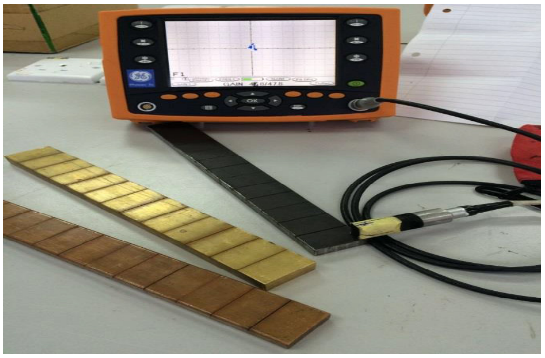
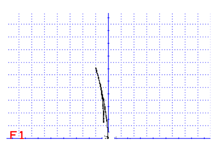
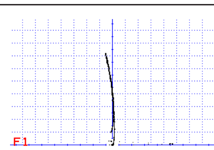
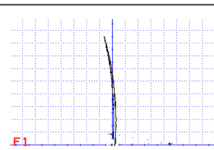
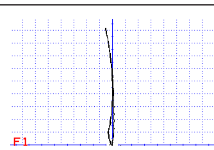
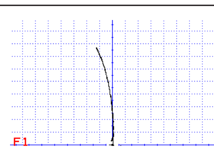


Figure 3. Eddy Current set.

Table 2. Conductivity for material specimen

Material	Brass	Copper	Mild steel
Conductivity (IACS%)	23.65	99.76	8.48

Table 3. The result for mild steel

Mild steel block				
Size of depth (mm)	Size of width (mm)	Gain (dB)	Signal display	Percentage signal %
1	0.2	45.1 dB		56%
1.5	0.4	45.1 dB		72%
2	0.6	45.1 dB		86%
2.5	0.8	45.1 dB		92%
1.5	1	45.1 dB		58%

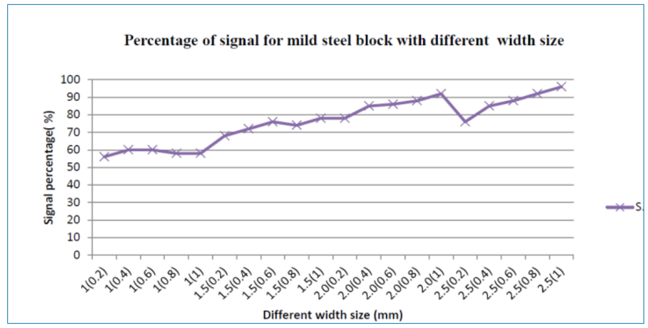


Figure 4. Percentage of signal for mild steel block.

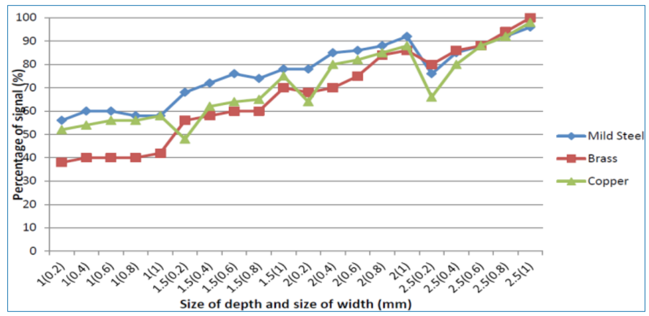


Figure 5. Comparison percentage of different materials.

by the weld probe. The inspection was conducted with a frequency of 50 kHz to 100 kHz. The phase was set to 100% FSH and gain was 50 dB (approximate). Figure 5 shows the results of the comparison, which indicate that the width defect and properties of the material influenced the Eddy Current signal.

High material conductivity causes a substantial flow of eddy currents on the surface. Thus, the magnitude and the spatial resolution of the signal detected by the EC probe for surface defects are enhanced for highly conductive metals[2,10].

4. Conclusion

In this paper detecting the deep cracks is investigated using Eddy Current (EC) Non-Destructive Testing (NDT). In fact, the detection sensitivity of EC-NDT depends on the interaction between the crack length direction and the EC flowing in the materials. In conventional EC-NDT systems, the induced currents are primarily generated along a single direction in the tested sample. The effect of the width defect and the properties of materials on Eddy Current signals can be detected based on deviations in the signal Eddy Current instrument. A weld probe was used to perform the inspection. The results prove that material conductivity and the size of cracks directly affect the Eddy Current signal.

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